Performance evaluation in land-based test facility

Trojan Marinex™ BWT 500

Filtration and UV disinfection

Trojan Technologies

Revised final report

November 2013

The expert in **WATER ENVIRONMENTS**

This report has been prepared under the DHI Business Management System certified by DNV and specifically for ballast water management system testing certified by Lloyd's Register	
Quality Management	BWMS Testing
ISO 9001	IMO Resolution MEPC.174(58) Annex part 2
Quality Management System certified according to DS/EN ISO 9001 by Det Norske Veritas, Business Assurance, Danmark A/S	

Approved by
29-11-2013 X Approved by Signed by: Jens Tørsløv

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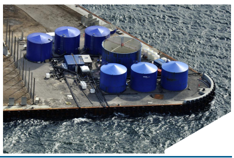

Prepared for Trojan Technologies

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Abbreviations

Abbreviation	Description
AVG	Average
BE	Biological efficacy
BWMS	Ballast water management system
CFU	Colony-forming units
CMFDA	Chloromethylfluorescein diacetate
DOC	Dissolved organic carbon
DNV	Det Norske Veritas
DPM	Disintegrations per minute
ETV	US-EPA, Environmental Technology Verification Program
FDA	Fluorescein diacetate
FR	Field replicate
IMO	International Maritime Organization
MEPC	Marine Environment Protection Committee
MM	Mineral materials
MPN	Most probable number
NTU	Nephelometric turbidity units
O&M	Operation and maintenance
POC	Particulate organic carbon
PSU	Practical salinity units
QAPP	Quality assurance project plan
SOP	Standard operating procedure
STD	Standard deviation
T0	Day 0 samples
T5	Day 5 samples
TSS	Total suspended solids
UVI	UV intensity
UV-T	UV transmittance
WET	Whole effluent toxicity

1 Executive summary

DHI provides independent performance evaluation of ballast water management systems (BWMS) for the approval process. The purpose of the performance evaluation is to assure that BWMS approved by administrations are capable of meeting the ballast water discharge standard in Regulation D-2 /1/, also known as the IMO D-2 standard, in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health. The United States Coast Guard Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters /4/ (§151.2030) establish a ballast water discharge standard similar to the IMO D-2 standard. According to the United States Coast Guard, the test set-up in land-based test cycles of BWMS must operate as described in the ETV protocol /5/.

The objective of this project was to conduct a performance evaluation of the Trojan Marinex™ BWT 500 in a land-based test facility with the aim to meet the testing requirements in Resolution MEPC.174(58) /2/. During testing of the Trojan Marinex™ BWT 500, the principles described in ETV protocol /5/ were followed and the applied QA/QC procedures were consistent with the U.S. Coast Guard requirements.

From April through July 2013, DHI conducted a land-based test of the Trojan Marinex™ BWT 500 with Det Norske Veritas (DNV) as classification society.

The basic treatment principles of Trojan Marinex™ BWT 500 are mechanical filtration by use of a filter unit, including twenty-four (24) super duplex custom-designed filter elements (32 µm each), and a ultra violet (UV) unit, including forty-eight (48) low pressure high efficiency UV lamps (500 Watts each). Mechanical filtration was only applied during ballast operations whereas disinfection with UV radiation was applied both during ballast and de-ballast operations.

Due to inadequate pump conditions at the test facility, a pump upgrade was made and three (3) additional tests were performed to demonstrate performance at flow rates exceeding 500 m^3/h. Therefore, thirteen biological efficacy (BE) test cycles and five operation and maintenance (O&M) test cycles were conducted. Trojan Marinex™ BWT 500 was operated independently by DHI staff during all BE and O&M test cycles. Trojan Technology staff was present at the test facility during all BE test cycles. Eight BE test cycles were conducted with brackish water, and five BE test cycles were conducted with fresh water. The total ambient water volume processed during the five O&M test cycles exceeded 10,000 m^3.

Trojan Marinex™ BWT 500 was tested at salinities ranging from 17 to 19 PSU (brackish water) and from 0.37 to 0.41 PSU (fresh water) at water temperatures ranging from approx. 8.4 to 22°C. The concentrations of total suspended solids (TSS), particulate organic carbon (POC), dissolved organic carbon (DOC) and mineral materials (MM) were in accordance with the minimum water quality characteristics in the IMO G8 guidelines and the ETV protocol in all BE test cycles. The densities of viable organisms and the number of phyla and species identified in the inlet and control discharge water were in accordance with the IMO G8 guidelines and the ETV protocol in all test cycles except for minor deviations that were not considered to influence the results. The average densities of viable organisms ≥50 µm ranged from approx. 233,600 to 761,400 organisms/m^3 in the inlet water, and from approx. 47,200 to 234,800 organisms/m^3 in the control discharge water. The average densities of viable organisms ≥10 and <50 µm determined by inverted microscopy varied from approx. 1,100 to 6,100 organisms/mL in the inlet water, and from 82 to approx. 1,800 organisms/mL in the control discharge water. In test cycles B-1/B-2 and B-6, the numbers of live organisms ≥10 and <50 µm in the control discharge were 96 (B-1/B-2) and 82 (B-6). Grazing by zooplankton (≥50 µm) is considered to be the reason for the observed density of organisms between ≥10 µm and <50 µm (mainly algae), which attained a level below the required 100 organisms/mL. The control discharge water contained 120,364 (B-1/B-2) and 54,247 (B-6) live organisms ≥50 µm (zooplankton) per m^3, confirming a high density of zooplankton capable of feeding on algae during the storage of the control discharge water. The low density of viable organisms in the size class ≥10 and <50 µm is thus considered without influence on the results.

Heterotrophic bacteria were present in concentrations from approx. 25,700 to approx. 67,900 CFU/mL in the inlet water, and from approx. 29,300 to >200,000 CFU/mL in the control discharge water.

Table 1.1 summarizes the numbers of viable organisms in water treated by Trojan Marinex™ BWT 500 at discharge, in which the viable organisms in the ≥10 and <50 µm size class were quantified by algal re-growth and addition of motile organisms without chlorophyll. DHI considers this quantification, which is also referred to as the most probable number (MPN) of proliferating algae and addition of chloromethylfluorescein diacetate/fluorescein diacetate (CMFDA/FDA) stained motile organisms without chlorophyll, the best available technique to determine viable organisms in the ≥10 and <50 µm size class after UV treatment. Table 1.2 summarizes the numbers of viable organisms in the ≥10 and <50 µm size class obtained by microscopic counting after staining with CMFDA and FDA and the results of measurements of algal primary production.

Table 1.1 Net flow rates, UV-T and UVI of inlet water and average numbers (three replicates) of viable organisms in treated water at discharge. Viable organisms ≥10 and <50 µm were quantified by the most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll

Test cycle	Net flowrate		UV-T (%)	UVI (mW/cm^2)	Organisms ≥50 µm per m^3	Organisms ≥10 and <50 µm per mL Algal re-growth + CMFDA/FDA-stained motile organisms	Organisms <10 µm Enterococci (CFU/100 mL)	Organisms <10 µm *E. coli* (CFU/100 mL)	Organisms <10 µm *V. cholerae* (CFU/100 mL)
	Treated (m^3/h)	Control (m^3/h)							
B-1	465	377	59	6.1	4.0	0.60	<1.0	<10	Absent
B-2	447	377	59	6.2	2.7	0.19	<1.0	<10	Absent
B-3	484	321	69	5.7	5.0	0.68	<1.0	<10	Absent
B-4	390	321	69	5.7	2.7	1.5	<1.0	<10	Absent
B-5	464	319	61	5.6	4.3	2.5	1.2	<10	Absent
B-6	397	401	59	5.7	0.33	0.51	<1.0	<10	Absent
B-7	558	319	59	5.6	3.7	4.2	<1.0	<10	Absent
B-8	551	319	59	5.7	3.0	0.85	<1.0	<10	Absent
F-1	515	318	48	3.0	6.7	9.6	<1.0	<1.0	Absent
F-2	502	499	48	3.1	1.3	3.5	<1.0	<1.0	Absent
F-3	482	499	48	3.1	0.67	0.20	<1.0	<1.0	Absent
F-4	471	318	46	2.9	0.0	0.38	<1.0	<1.0	Absent
F-5	490	318	46	3.0	0.0	0.38	<1.0	<1.0	Absent
Require-ments	-	-	-	-	<10	<10	<100	<250	<1

CFU Colony-forming units

Table 1.2 Average numbers (three replicates) of viable organisms ≥10 and <50 µm quantified by microscopic counting after staining with CMFDA and FDA and measurements of algal primary production

Test cycle	Organisms ≥10 and <50 µm	
	Microscopy after CMFDA/FDA staining (organisms/mL)	Primary production* (% decrease)
B-1	327	96
B-2	328	98
B-3	55	100
B-4	71	100
B-5	137	100
B-6	48	100
B-7	33	100
B-8	33	100
F-1	1,957	96
F-2	564	95
F-3	567	94
F-4	235	99
F-5	236	98

* Primary production is expressed as the percentage reduction of the primary production in inlet water samples

Practical experience from previous land-based tests conducted by DHI indicates that UV-based BWMS are frequently unable to meet the ballast water discharge standard if the treatment performance of organisms ≥10 and <50 µm is evaluated solely on the basis of microscopy after staining with CMFDA and FDA. These stains react with non-specific esterases and intact stained cells fluoresce under the microscope. The unsuitability of the microscopic counting of CMFDA/FDA-stained cells for evaluation of UV effects can be explained biologically as follows: UV radiation causes damage to the cell DNA and prevents cell proliferation but the esterase enzyme activity and the cell membrane may stay intact for several days. Consequently, the total numbers of viable organisms ≥10 and <50 µm obtained by microscopic counting after CMFDA/FDA-staining, which markedly exceed the ballast water discharge standard, were disregarded in the evaluation. Algal re-growth determined as the MPN of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll was applied in this land-based test for the evaluation of treatment performance in relation to organisms ≥10 and <50 µm (data in Table 1.1). In the land-based test of Trojan Marinex™ BWT 500, the algal phyla and species capable of growing under the conditions applied in the algal re-growth assay represented 75-100% (brackish water test cycles) and 63-71% (freshwater test cycles) of the phyla and species identified in the inlet water.

The performance evaluation based on algal re-growth and addition of motile organisms without chlorophyll for the organisms ≥10 and <50 µm (Table 1.1) leads to the conclusion that the Trojan Marinex™ BWT 500 complies with the ballast water discharge standard in all test cycles.

2 Introduction

DHI is an independent, international consulting and research organisation established in Denmark and today represented in all regions of the world with a total of more than 1,000 employees. Our objectives are to advance technological development, governance and competence in the fields of water, environment and health. DHI works with governmental agencies and authorities, contractors, consultants and numerous industries.

DHI provides independent performance evaluation of ballast water management systems (BWMS) for the approval process. DHI has no involvement, intellectual or financial, in the mechanics, design or marketing of the products and technologies that are being evaluated. To ensure that DHI's tests are uncompromised by any real or perceived individual or team bias relative to test outcomes, DHI's test activities are subject to rigorous quality assurance (QA), quality control (QC) and documentation. DHI's quality management system is certified according to ISO 9001 by Det Norske Veritas (DNV). The certification is facilitated by the implementation of the DHI Business Management System.

For an application for final approval, the IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments /1/ requires a performance evaluation of BWMS according to the principles laid down in Resolution MEPC.174(58) /2/, generally referred to as the IMO G8 guidelines, and, for systems that make use of active substances, also Resolution MEPC.169(57) /3/, generally referred to as the IMO G9 guidelines. The purpose of the performance evaluation is to assure that BWMS approved by administrations are capable of meeting the ballast water discharge standard in Regulation D-2 /1/, also known as the IMO D-2 standard, in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health. The United States Coast Guard Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters /4/ (§151.2030) establish a ballast water discharge standard similar to the IMO D-2 standard.

DHI obtained acceptance as sub-laboratory to the accepted Independent Laboratory, DNV Norway, by Letter of Acceptance from the United States Coast Guard (U.S. Coast Guard) dated 11 June 2013. DHI was not recognized as an accepted sub-laboratory according to the U.S. Coast Guard standards when the land-based testing with Trojan Marinex™ BWT 500 were initiated (April 2013), and DHI shall not be responsible if this fact is taken into account in the evaluation by the U.S. Coast Guard. During testing of the Trojan Marinex™ BWT 500, the principles described in ETV protocol /5/ were followed and the applied QA/QC procedures were consistent with the U.S. Coast Guard requirements.

This report describes a series of 13 land-based test cycles conducted by DHI from April 2013 to July 2013 with Trojan Marinex™ BWT 500.

3 Objective

The objective of this project was to conduct a performance evaluation of the Trojan Technologies BWMS Trojan Marinex™ BWT 500 at a land-based test facility in accordance with the requirements for type approval testing in Resolution MEPC.174(58) /2/.

4 Classification society

The classification society appointed by the client for inspection and certification of the project is:

Det Norske Veritas A/S (DNV)
Veritasveien 1
NO-1363 Høvik
Norway

5 Client

The client requesting the performance evaluation is:

Trojan Technologies
London, Ontario N5V 4T7
Canada

The client is the manufacturer of the BWMS Trojan Marinex™ BWT 500.

6 Testing laboratory

DHI established a land-based test facility in Hundested, Denmark, in June 2010. A description of the test facility is available in the Test Plan in Appendix A.

DHI was recognized as a sub-laboratory to the Independent Laboratory with DNV as the accepted test facility by Letter of Acceptance from U.S. Coast Guard dated 11 June 2013. DHI's Environmental Laboratory has an accreditation according to ISO 17025, which includes biological analyses related to performance evaluation of BWMS and ecotoxicological studies. Furthermore, the laboratory is authorized to carry out ecotoxicological studies in compliance with the OECD Principles of Good Laboratory Practice (GLP) (Appendix H).

DHI's Environmental Laboratory and staff normally analyse all samples collected during the performance evaluation of BWMS. If required, specialized chemical analyses of, e.g., active substances or disinfection by-products, are conducted by a subcontractor.

The performance evaluation of Trojan Marinex™ BWT 500 was conducted by DHI at the following facilities:

DHI Environmental Laboratory
Agern Allé 5
DK-2970 Hørsholm
Denmark

DHI Maritime Technology Evaluation Facility
Færgevejen 18
DK-3390 Hundested
Denmark

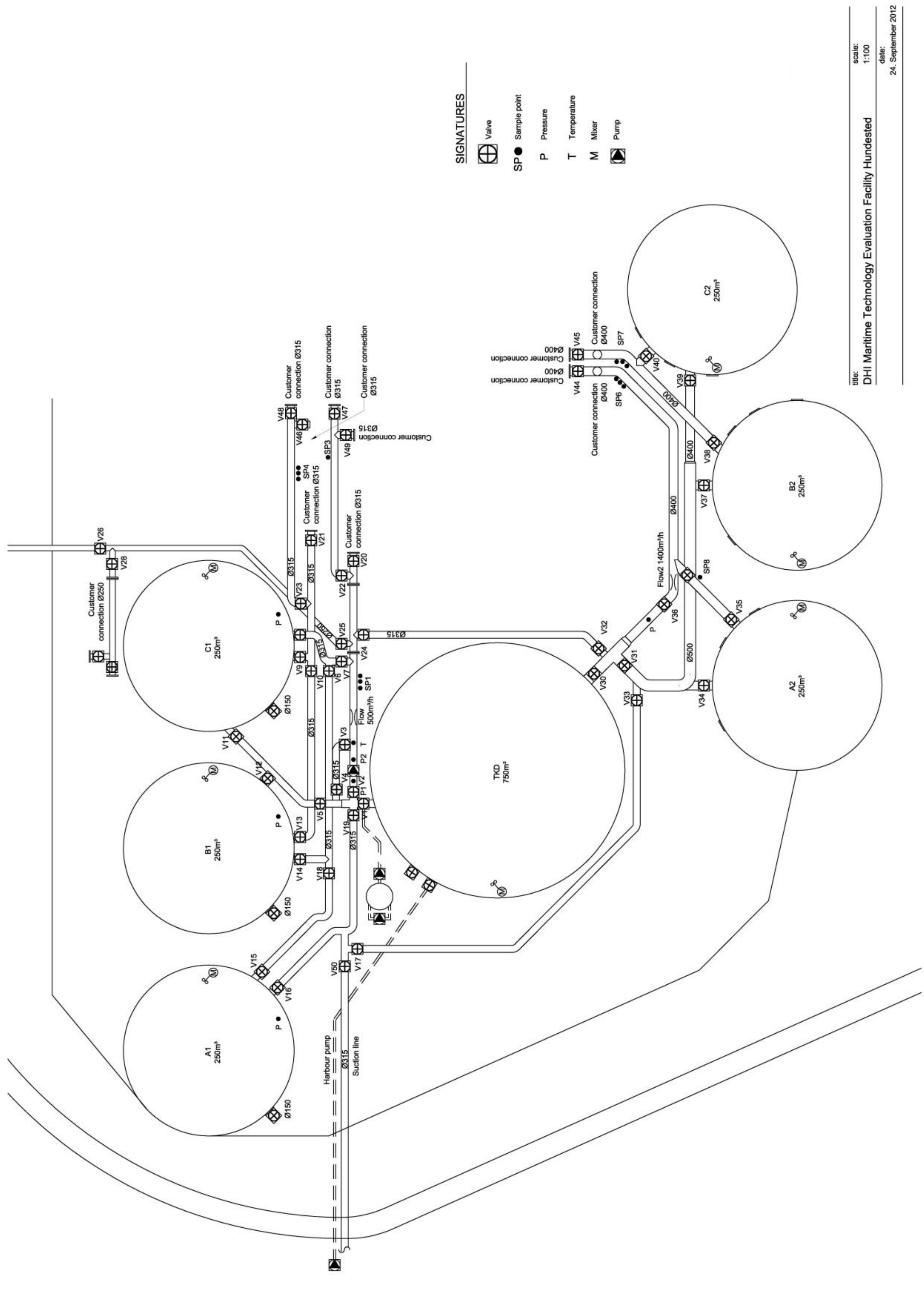

Figure 6.1 DHI Maritime Technology Evaluation Facility, Hundested, Denmark

7 Ballast water management system

The basic treatment principles of Trojan Marinex™ BWT 500 are mechanical filtration by use of a filter unit, including twenty-four (24) super duplex custom-designed filter elements (32 µm each), and a ultra violet (UV) unit, including forty-eight (48) low pressure high efficiency UV lamps (500 Watts each). Mechanical filtration was only applied during ballast operations whereas disinfection with UV radiation was applied both during ballast and de-ballast operations. The Trojan Marinex™ BWT 500 BWMS was tested with a flow rate before the filter between 487 and 645 m^3/h and with a flow rate after the filter between 390 and up to 558 m^3/h. A technology and process description of Trojan Marinex™ BWT 500 is enclosed in Appendix B of the Test Plan (Appendix A). A revised version of the technology and process description is provided in Amendment No. 1 (Appendix A).

7.1 Performance claim and BWMS limitation

Before land-based testing was initiated, Trojan Technologies described a technology performance claim for the Trojan Marinex™ BWT 500, which was included in Section 4.1 of the Test Plan (Appendix A). In this performance claim, it was stated that, at total rated capacity, the Trojan Marinex™ BWT 500 could be expected to achieve biological performance according to the ballast water discharge standard /1/, /4/.

8 Experimental design

The Trojan Marinex™ BWT 500 performance evaluation involved physical and biological characterization of water upon ballasting (inlet water) and comparison of organisms in control versus treated water immediately following treatment and at discharge after five days storage and second treatment.

8.1 Trial period, installation and operation of Trojan Marinex™ BWT 500

Due to inadequate pump conditions at the test site, a pump upgrade was completed and three (3) additional tests were performed to allow demonstration of performance at flow rates in excess of 500 m^3/h. A total of 13 biological efficacy (BE) test cycles and five operation and maintenance (O&M) test cycles were conducted throughout the test period. Eight BE test cycles were conducted in brackish water (B-1 to B-8), and five BE test cycles were conducted in fresh water (F-1 to F-5). All O&M test cycles were conducted in brackish water.

Before initiating the BE test cycles, a test, in which brackish water was pumped through the BWMS, was performed to confirmed that the Trojan Marinex™ BWT 500 was installed correctly and was operating in accordance with the requirements of Trojan. Furthermore, the test was used for training DHI staff in the independent operation of the BWMS.

Trojan decided not to conduct an actual commissioning test as outlined in the ETV protocol with a commissioning verification report.

The Trojan Marinex™ BWT 500 was operated independently by DHI staff during all BE and O&M test cycles. Trojan staff was present at the test facility during all BE test cycles. Trojan's log on adjustments, service and maintenance actions related to the BWMS during the trial period is enclosed in Appendix B. All adjustment, service and maintenance actions carried out by Trojan staff were witnessed by DHI staff.

8.2 Biological efficacy verification testing

8.2.1 BWMS treatment process

The BE test cycles were conducted by use of the source tank (Tank D), control tank (Tank A1) and one retention tank per test cycle (Tank B1 or C1) (Figure 6.1).

During ballast operation, the treatment of the test water with Trojan Marinex™ BWT 500 involved the following steps:

1. A fraction of the test water contained in the source tank was pumped to in-line treatment in the BWMS and further to one of the retention tanks (treated water) until at least 200 m^3 of water had been treated by the BWMS (mechanical filtration and UV radiation).
2. Another fraction of the same test water (minimum 200 m^3) was pumped directly into the control tank, bypassing the BWMS (control water). The control water served as a control of the BWMS performance.
3. Piping system and sample ports were cleaned (DHI SOP 30/1763).

The Trojan Marinex™ BWT 500 had a total rated capacity of approx. 500 m^3/h for most of the tests after the mechanical filter (see Table 8.1), i.e. treatment of at least 200 m^3 of test water took approx. 25 minutes.

During ballasting, the flow rate, pressure, temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks were recorded automatically (DHI SOP 30/1764).

Samples were collected before and after first treatment by use of the relevant sample ports. Sampling was initiated when the flow rate had reached steady-state conditions, i.e. up to 2 minutes from the start of operation (DHI SOPs 30/1738 and 30/1762). The samples were labelled (DHI SOP 30/1750).

8.2.2 Storage of treated and untreated test water

Following the treatment of the test water in the BWMS, the treated water was stored in the retention tank for at least 5 days ± 4 hours. The same storage time was applied for the control water.

8.2.3 Second treatment and discharge of test water

1. Treated water contained in the retention tank was pumped through the BWMS for second treatment, after which it was discharged into the harbour (treated discharge water).
2. Control water contained in the control tank was discharged into the harbour (control discharge water).
3. The retention tanks, piping system and sample ports were cleaned (DHI SOP 30/1763).

During de-ballasting, the flow, pressure, water temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks were recorded automatically (DHI SOP 30/1764).

Samples of the treated discharge water were collected by use of the sampling ports on the BWMS discharge line whereas samples of the control discharge water were collected by use of sampling ports on the test facility discharge line. Isokinetic sampling methodology with fixed sample volumes was applied according to the principles described in MEPC.173(58) (G2) /6/.

8.2.4 Biological efficacy test cycles

An overview of dates, time periods, treated volumes and corresponding flow rates used for all 13 BE test cycles is presented in the table below.

The flow rates for the control water were slightly lower than the flow rates for the water treated by the BWMS (Table 8.1) due to a mistake in the manual operation of the control flow.

Table 8.1 Details for inlet and discharge operations for biological efficacy test cycles

Test cycle	Type	Inlet					Discharge	
		Date & time	UV-T (%)	UVI (mW/cm^3)	Treated volume and flow rate*	Net flow rate after filter	Date & time	Treated volume and flow rate*
B-1	BWMS	2013.04.18 11:05-11:33	59	6.1	217 m^3 544 m^3/h	465 m^3/h	2013.04.23 11:16-11:37	195 m^3 546 m^3/h
	Control	2013.04.18 13:26-13:58		-	213 m^3 377 m^3/h	-	2013.04.23 13:38-14:17	204 m^3 325 m^3/h
B-2	BWMS	2013.04.18 12:36-13:05	59	6.2	216 m^3 535 m^3/h	447 m^3/h	2013.04.23 13:06-13:28	200 m^3 545 m^3/h
	Control	2013.04.18 13:26-13:58		-	213 m^3 377 m^3/h	-	2013.04.23 13:38-14:17	204 m^3 325 m^3/h
B-3	BWMS	2013.06.20 08:34-09:02	69	5.7	218 m^3 572 m^3/h	484 m^3/h	2013.06.25 11:09-11:30	192 m^3 507 m^3/h
	Control	2013.06.20 10:42-11:21		-	216 m^3 321 m^3/h	-	2013.06.25 13:21-13:53	204 m^3 362 m^3/h
B-4	BWMS	2013.06.20 10:04-10:37	69	5.7	208 m^3 493 m^3/h	390 m^3/h	2013.06.25 12:33-12:56	185 m^3 510 m^3/h
	Control	2013.06.20 10:42-11:21		-	216 m^3 321 m^3/h	-	2013.06.25 13:21-13:53	204 m^3 362 m^3/h
B-5	BWMS	2013.06.27 09:13-09:40	61	5.6	209 m^3 514 m^3/h	464 m^3/h	2013.07.02 09:12-09:31	172 m^3 510 m^3/h
	Control	2013.06.27 09:51-10:29		-	207 m^3 319 m^3/h	-	2013.07.02 11:36-12:14	199 m^3 322 m^3/h
B-6	BWMS	2013.07.11 10:16-10:51	59	5.7	225 m^3 487 m^3/h	397 m^3/h	2013.07.16 13:31-13:56	198 m^3 489 m^3/h
	Control	2013.07.11 11:35-12:06		-	218 m^3 401 m^3/h	-	2013.07.16 14:21-15:00	211 m^3 320 m^3/h
B-7	BWMS	2013.07.18 10:18-10:41	59	5.6	214 m^3 645 m^3/h	558 m^3/h	2013.07.23 10:01-10:21	188 m^3 554 m^3/h
	Control	2013.07.18 12:33-13:12		-	216 m^3 319 m^3/h	-	2013.07.23 07:56-08:37	207 m^3 320 m^3/h
B-8	BWMS	2013.07.18 11:43-12:06	59	5.7	211 m^3 624 m^3/h	551 m^3/h	2013.07.23 11:40-12:01	181 m^3 524 m^3/h
	Control	2013.07.18 12:33-13:12		-	216 m^3 319 m^3/h	-	2013.07.23 07:56-08:37	206 m^3 320 m^3/h
F-1	BWMS	2013.05.02 10:06-10:33	48	3.0	223 m^3 543 m^3/h	515 m^3/h	2013.05.07 09:42-10:05	200 m^3 503 m^3/h
	Control	2013.05.02 10:54-11:30		-	202 m^3 318 m^3/h	-	2013.05.07 12:48-13:26	193 m^3 320 m^3/h

Test cycle	Type	Inlet					Discharge	
		Date & time	UV-T (%)	UVI (mW/cm^3)	Treated volume and flow rate*	Net flow rate after filter	Date & time	Treated volume and flow rate*
F-2	BWMS	2013.05.23 10:01-10:28	48	3.1	226 m^3 530 m^3/h	502 m^3/h	2013.05.28 11:32-11:55	191 m^3 507 m^3/h
	Control	2013.05.23 12:30-12:57		-	207 m^3 499 m^3/h	-	2013.05.28 14:32-15:07	199 m^3 362 m^3/h
F-3	BWMS	2013.05.23 10:42-12:08	48	3.1	209 m^3 523 m^3/h	482 m^3/h	2013.05.28 13:37-13:59	183 m^3 516 m^3/h
	Control	2013.05.23 12:30-12:57		-	207 m^3 499 m^3/h	-	2013.05.28 14:32-15:07	199 m^3 362 m^3/h
F-4	BWMS	2013.05.30 11:07-11:24	46	2.9	212 m^3 554 m^3/h	471 m^3/h	2013.06.04 11:10-11:31	176 m^3 520 m^3/h
	Control	2013.05.30 12:44-13:21		-	206 m^3 318 m^3/h	-	2013.06.04 13:16-13:54	198 m^3 320 m^3/h
F-5	BWMS	2013.05.30 12:12-12:37	46	3.0	204 m^3 564 m^3/h	490 m^3/h	2013.06.04 12:42-13:03	171 m^3 519 m^3/h
	Control	2013.05.30 12:44-13:21		-	206 m^3 318 m^3/h	-	2013.06.04 13:16-13:54	198 m^3 320 m^3/h

* Flow rate based on time and treated volume logged during ballast operation at the DHI test facility. Treated volume includes the 3 m^3 used for evaluation of organisms in the size class ≥ 50 µm.

For each BE test cycle, additional details on addition of organisms, recording of power consumption, UV intensities etc. are available in the data logging in Appendix C.

Samples for whole effluent toxicity (WET) testing were taken during test cycle B-1. A separate report was prepared for the WET testing /7/.

8.3 Test water and challenge conditions in BE verification testing

Source water means the body of water, from which water is drawn for the land-based test. The IMO G8 guidelines /2/ and the ETV protocol /5/ describe three distinct water types that may be applied in the land-based test:

- Fresh water (salinity <1 PSU)
- Brackish water (salinity 10-20 PSU)
- Marine water (salinity >32-36 PSU)

The BE test cycles with Trojan Marinex™ BWT 500 were performed with brackish and fresh water.

For BE test cycles with brackish water, the source water was collected immediately south of the pier adjacent to the test facility (DHI SOP 30/1735); under normal conditions, the natural salinity of the source water is 15-20 PSU.

For BE test cycles with fresh water, the source water was collected in the Arresø Canal (DHI SOP 30/1736). Organism densities in the collected fresh water often exceed the minimum criteria for live organisms in the test water with an order of magnitude allowing for dilution of the natural water with potable water.

8.3.1 Test water – water quality characteristics

Test water (equivalent to the term challenge water /4/, /5/) means the inlet water as contained in the source tank immediately prior to treatment. In land-based tests, source water may be adjusted to achieve the required challenge conditions. The test water was adjusted to meet the required water quality parameters in Table 8.2.

Table 8.2 Minimum water quality characteristics according to the IMO G8 guidelines /2/ and, in parentheses, the ETV protocol /5/

Parameter	Test water		
	Fresh <3 (<1) PSU	Brackish 3-32 (10-20) PSU	Marine >32 (28-36) PSU
Dissolved organic carbon (DOC)	>5 (≥6) mg/L	>5 (≥6) mg/L	>1 (≥6) mg/L
Particulate organic carbon (POC)	>5 (≥4) mg/L	>5 (≥4) mg/L	>1 (≥4) mg/L
Total suspended solid (TSS) Mineral materials (MM) ≥ 20 mg/L	>50 (≥24) mg/L	>50 (≥24) mg/L	>1 (≥24) mg/L

If necessary in order to obtain the required water quality parameters, the concentrations of dissolved organic carbon (DOC), particulate organic carbon (POC) and mineral materials (MM) were increased by adding sodium citrate (DOC), starch (POC) and kaolin clay (MM) (DHI SOP 30/1737).

8.3.2 Test water – biological organism conditions

The test water was prepared to meet the required densities of live organisms in Table 8.3.

Table 8.3 Minimum criteria for densities of live organisms in the test water according to the IMO G8 guidelines /2/ and the ETV protocol /5/

Organism size class	Total concentration	Diversity
≥50 µm	10^5 organisms/m^3	5 species across 3 phyla
≥10 µm and <50 µm	10^3 organisms/mL	5 species across 3 phyla
<10 µm	10^4/mL as culturable aerobic heterotrophic bacteria	Not applicable

If necessary in order to obtain the stated minimum criteria, the densities of live organisms were increased by adding harvested indigenous organisms and/or cultured species (DHI SOP 30/1734). Addition of harvested and/or cultured species was recorded in the data logging (Appendix C). Heterotrophic bacteria were present in the test water in densities exceeding the minimum criteria presented in Table 8.3.

The required minimum densities of live organisms in the control discharge water are presented in Table 8.4.

Table 8.4 Minimum criteria for densities of live organisms in the control discharge water according to the IMO G8 guidelines /2/ and the ETV protocol /5/

Organism size class	Total concentration
≥ 50 µm	100 organisms/m^3 (IMO and ETV)
≥10 µm and < 50 µm	100 organisms/mL (IMO and ETV)
<10 µm	5×10^2/mL as culturable aerobic heterotrophic bacteria (ETV)

8.4 Operation and maintenance testing

Five O&M test cycles were conducted with Trojan Marinex™ BWT 500. The O&M test cycles were conducted in ballast operation mode with mechanical filtration and UV disinfection. The O&M test cycles were conducted with ambient water conditions. The maximum flow rate that can be provided during O&M testing at the DHI test facility is approx. 450-500 m^3/h.

An overview of the dates, time periods, treated volumes and average flow rates used in the five O&M test cycles is presented in Table 8.5.

Table 8.5 Details for operation and maintenance (O&M) test cycles

Test cycle	Date	Time	Volume	Average flow rate*
O&M-1	2013.05.27	10:15-14:30	2,043 m^3	480 m^3/h
O&M-2	2013.06.19	10:50-16:15	2,018 m^3	371 m^3/h
O&M-3	2013.06.24	11:55-15:59	2,023 m^3	497 m^3/h
O&M-4	2013.06.26	09:10-13:22	1,923 m^3	458 m^3/h
O&M-5	2013.07.01	11:39-15:48	2,099 m^3	504 m^3/h

* Average flow rate logged during ballast operation by flow meter in piping before the Trojan Marinex™ BWT 500 (inlet to mechanical filter)

The total water volume processed during the five O&M test cycles exceeded 10,000 m^3. The Trojan Marinex™ BWT 500 BWMS caused no mechanical failures or alarms during O&M testing. For each O&M test cycle, additional details regarding recordings of power consumption, UV intensities etc. are available in the data logging enclosed in Appendix D.

9 Sampling and analyses in BE verification testing

9.1 Sample overview

Table 9.1 Overview of sampling and purpose of samples

Parameter	Inlet water to BWMS and control tank	Treated water on day 0 (after 1st treatment)	Treated discharge water (after 2nd treatment)	Control discharge water	Sample collection	Sample volume
Ballast and de-ballast operations						
Volume	×	×	×	×	Continuous	Online
Pressure	×	×	×	×	Continuous	Online
Flow rate	×	×	×	×	Continuous	Online
Other parameters*	×	×	×	×	Continuous	Online
Water quality conditions						
Temperature, salinity, turbidity, pH, dissolved oxygen	×	×	×	×	Continuous	Online
TSS, DOC**, POC** and UV-T***	×	×	×	×	Discrete grab (3 replicates; start, middle, end)	Approx. 0.5 L
Concentrations of viable organisms						
Viable organisms ≥50 µm/m^3	×	×	×	×	Discrete (3 replicates; time integrated)	Inlet: 20 L After 1st treatment and during discharge: 1 m^3
Viable organisms ≥10 and <50 µm/mL	×	×	×	×	Discrete 3 replicates; each representing approx. ⅓ of the operation period)	Approx. 10 L
Viable organisms <10 µm/mL	×	×	×	×	Discrete grab (3 replicates; start, middle, end)	Approx. 0.5 L
Whole effluent toxicity (WET)	-	-	×****	×****	Discrete (time integrated)	Approx. 25 L

* Operational parameters to ensure that the system has been operated correctly and in accordance with the Operation and Maintenance manual
** Measured in inlet and discharge samples
*** UV transmittance at 254 nm, 1 cm, measured in inlet samples
**** Only in BE test cycle B-1

Flow-integrated samples were collected. The samples were stored in thermo boxes with cooler bricks in the dark from the time of collection until handling of the samples at the DHI Environmental Laboratory.

9.2 Inlet water and treated water after 1st treatment

Table 9.2 Sampling and analysis of inlet water to BWMS and control tank

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Primary production (algae)	30/1702	DHI
Re-growth assay (algae)	30/1704	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1706	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical properties		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
UV transmittance at 254 nm, 1 cm	30/1770	DHI

Table 9.3 Sampling and analysis of treated water after 1st treatment

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Primary production (algae)	30/1702	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1706	DHI
Physical/chemical properties		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS	30/1768	DHI

9.3 Treated discharge water and control discharge water

Table 9.4 Sampling and analysis of treated discharge water after 2nd treatment

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Primary production (algae)	30/1702	DHI
Re-growth assay (algae)	30/1704	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1706	DHI
Vibrio cholerae	30/1707	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical properties		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
Whole effluent toxicity (WET) (only test cycle B-1)	30/326 (ISO/TC 147/SC 5 N 708 Draft) + 30/364 (OECD 212)	DHI

Table 9.5 Sampling and analysis of control discharge water

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Primary production (algae)	30/1702	DHI
Re-growth assay (algae)	30/1704	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1706	DHI
Vibrio cholerae	30/1707	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical properties		
Temperature, pH, O2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
Whole effluent toxicity (WET) (only test cycle B-1)	30/326 (ISO/TC 147/SC 5 N 708 Draft) + 30/364 (OECD 212)	DHI

9.4 Analyses

9.4.1 Physical/chemical analyses

The following physical/chemical analyses were conducted (DHI SOPs 30/1764 and 30/1770):

- pH
- Turbidity
- Dissolved oxygen
- Ballast system pressure
- Ballast system flow rates
- UV transmittance at 254 nm, 1 cm
- Water volume in retention tanks

9.4.2 Organism size class ≥50 µm

The concentrations of live organisms ≥50 µm in minimum dimension were determined by use of a stereo microscope and a counting chamber (DHI SOP 30/1700). Viable organisms were enumerated by use of standard movement and response stimuli technique. The viable organisms were characterized according to broad taxonomic groups such as crustaceans (e.g. copepods), molluscs, rotifers, nematodes, etc.

For treated discharge samples, the total sample volume of each of the three field replicates (3 × 1 m^3 concentrated samples) was analysed.

9.4.3 Organism size class ≥10 µm and <50 µm

The concentrations of organisms and the presence of taxonomic groups in the inlet water were determined by inverted microscopy (DHI SOP 30/1701). Inverted microscopy was also used to determine the taxonomic groups of algae capable of growing under the conditions applied in the algal re-growth assay.

The numbers of viable organisms ≥10 µm and <50 µm in minimum dimension were determined by use of three different methods:

1. Microscopic counting after staining with chloromethylfluorescein diacetate (CMFDA) and fluorescein diacetate (FDA) (recommended in the ETV protocol /5/)
2. Most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll
3. Measurement of algal primary production

Compliance with the pass criterion was verified by use the total of viable organisms determined by the most probable number (MPN) obtained in an algal re-growth assay and addition of viable CMFDA/FDA-stained motile organisms ≥10 µm and <50 µm in minimum dimension without chlorophyll (these organisms are not detected in the re-growth assay which is based on measurements of fluorescence).

Microscopic counting after staining with CMFDA and FDA

CMFDA and FDA were added to a subsample and, after incubation, the subsample was examined by use of a microscope under epifluorescence. Organisms labelled by either CMFDA or FDA were considered viable as described in DHI SOP 30/1701.

Most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll

- Viable algae were quantified by measuring the most probable number (MPN) of proliferating algae in an algal re-growth assay. The algal re-growth assay includes planktonic algae without reference to size and, thus, it is not limited to the ≥10 µm and <50 µm size class. A dilution series was prepared by adding aliquots of subsample to test tubes with liquid medium. The test tubes were incubated for 14 days in light at ambient temperature. The concentrations of viable algae in the inlet water, control discharge water and treated discharge water were determined by measuring of the fluorescence in the test tubes before and after incubation (DHI SOP 30/1704). The MPN obtained after 14 days of incubation was recorded.
- CMFDA/FDA-stained motile organisms without chlorophyll enumerated by microscopy (DHI SOP 30/1701) were recorded as a separate group.
- The final result from this method was obtained by adding up the MPN and the number of CMFDA/FDA-stained motile organisms without chlorophyll.

Algal primary production

The algal primary production was determined by measuring the ^{14}C fixed by photosynthesis. The algal primary production assay includes planktonic algae without reference to size and, thus, it is not limited to the ≥10 µm and <50 µm size class. For each field replicate, $NaH^{14}CO_3$ (2 µCi) was added to two subsamples. These subsamples were incubated for approx. 75 min under light from a light panel at ambient temperature. After incubation, the samples were filtered onto Whatman GF/D filters. The filters were transferred to glass vials and acid was added directly to the filters to release $^{14}CO_2$. The ^{14}C activity remaining in the algae on the filters after acidification was quantified by liquid scintillation counting according to DHI SOP 30/1702.

9.4.4 Organism size class <10 µm (bacteria)

The concentrations of heterotrophic aerobic bacteria were determined according to ISO 6222 (DHI SOP 30/1706). *E. coli* and enterococci were analysed (DHI SOP 30/1708). *Vibrio cholerae* was analysed according to ISO 21872 (DHI SOP 30/1707).

10 Results from biological efficacy test cycles

10.1 Inlet and control discharge water

10.1.1 Physical-chemical parameters

For all 13 BE test cycles, the physical-chemical conditions of inlet and control discharge water are summarized in Table 10.1 and Table 10.2. Detailed data on TSS, POC, DOC, MM and UV transmittance are available in Appendix E. Detailed online measurement data are available in the data logging in Appendix C.

Table 10.1 Inlet and control discharge water. Average concentrations (three replicates) of total suspended solids (TSS), particulate organic carbon (POC), dissolved organic carbon (DOC), mineral materials (MM) and average measurements of UV transmittance (UV-T).

Test cycle	Sample	TSS (mg/L)	POC (mg/L)	DOC (mg/L)	MM (mg/L)*	UV-T (%)
B-1 and B-2	Inlet	60	5.5	6.0	54	59/88**
	Control discharge	5.6	0.6	3.8	4.9	-
B-3 and B-4	Inlet	57	7.6	6.7	50	69/87**
	Control discharge	4.8	0.14	3.5	4.7	-
B-5	Inlet	61	5.6	6.8	55	61/88**
	Control discharge	2.4	0.45	2.9	5.8	-
B-6	Inlet	74	6.8	6.9	67	59/88**
	Control discharge	2.0	0.98	5.7	1.0	-
B-7 and B-8	Inlet	61	5.5	8.3	55	59/87**
	Control discharge	2.1	0.99	7.0	1.1	-
F-1	Inlet	61	5.7	8.2	55	48/71**
	Control discharge	14	0.62	9.6	13	-
F-2 and F-3	Inlet	56	6.2	8.0	49	48/72**
	Control discharge	11	0.94	5.2	9.8	-
F-4 and F-5	Inlet	61	6.0	8.2	55	46/73**
	Control discharge	7.8	0.38	7.8	7.5	-
Require-ments	Fresh water and brackish water (inlet)***	>50 / ≥24	>5 / ≥4	>5 / ≥6	- / ≥20	-
	Marine water (inlet)***	>1 / ≥24	>1 / ≥4	>1 / ≥6	- / ≥20	-

* MM determined as the difference between TSS and POC as described in Section 5.4.6.1 of the ETV protocol /5/

** Filtered through a 0.45-µm syringe filter when received at the DHI laboratory

*** Minimum water quality characteristics according to the IMO G8 guidelines /2/ and the ETV protocol /5/

Table 10.2 Inlet and control discharge water. Average measurements of dissolved oxygen, pH, salinity, temperature and turbidity.

Test cycle	Sample	Oxygen (%)	pH	Salinity (PSU)	Temp. (°C)	Turbidity (NTU)
B-1 and B-2	Inlet control	109	7.9	19	8.4	31
	Control discharge	69	7.5	19	9.8	4.6
B-3 and B-4	Inlet control	98	8.3	18	18	32
	Control discharge	19	7.3	19	19	0.15
B-5	Inlet control	95	8.0	18	17	36
	Control discharge	15	7.3	18	17	1.7
B-6	Inlet control	96	8.0	17	18	40
	Control discharge	36	7.4	17	20	0.97
B-7 and B-8	Inlet control	97	8.0	18	19	38
	Control discharge	57	7.5	18	22	1.5
F-1	Inlet control	105	8.0	0.37	9.7	33
	Control discharge	93	7.8	0.37	14	15
F-2 and F-3	Inlet control	93	8.2	0.37	14	30
	Control discharge	81	8.2	0.41	16	10
F-4 and F-5	Inlet control	101	8.3	0.41	15	37
	Control discharge	85	8.2	0.41	17	9.1
Require-ments	Fresh water*	-	-	<3 / <1	-	-
	Brackish water*	-	-	3-32 / 10-20	-	-
	Marine water*	-	-	>32 / 28-36	-	-

* Minimum water quality characteristics according to the IMO G8 guidelines /2/ and the ETV protocol /5/
PSU Practical salinity units
NTU Nephelometric turbidity units

In all test cycles, the concentrations of TSS, POC, DOC and MM were in accordance with the minimum water quality characteristics in the IMO G8 guidelines and the ETV protocol (Table 8.2). The measured salinities were within the salinity ranges prescribed by the IMO G8 guidelines and the ETV protocol.

10.1.2 Biological parameters

The densities of viable organisms in the inlet and control discharge water were in accordance with the IMO G8 guidelines and the ETV protocol (as described in Section 8.3.2) in all test cycles except for the test cycles B-1, B-2 and B-6, in which the control discharge requirement of viable organisms in the size group ≥10 µm and < 50 µm could not be fulfilled (Table 10.4). Detailed data from the biological efficacy analyses are available in Appendix E.

10.1.2.1 Organism size class ≥50 µm

The average densities of viable organisms ≥50 µm in the inlet water ranged from approx. 233,600 to 761,400 organisms/m^3 in the brackish water test cycles and from approx. 233,900 to 440,800 organisms/m^3 in the freshwater test cycles (Table 10.3). In the control discharge water, the average densities of viable organisms ranged from approx. 47,200 to 120,300 organisms/m^3 in the brackish water test cycles and from approx. 136,100 to 234,800 organisms/m^3 in the freshwater test cycles.

In the inlet water, the majority of the organisms ≥50 µm were identified as belonging to groups of crustaceans (copepods, nauplii, artemia), rotifers and to some extent molluscs. In each test cycle, the diversity of organisms ≥50 µm was in accordance with the recommendation of five different species divided between three phyla (as described in Section 8.3.2).

A complete taxonomic overview of the phyla and species identified in inlet and control discharge water samples in each of the 13 BE test cycles is available in Appendix E, Table E.7.

Table 10.3 Inlet and control discharge water. Total sample volumes and average concentrations of viable organisms in the size class ≥50 µm. Average of nine or six replicates in inlet water and average of three replicates in control discharge water.

Test cycle	Sample	Total sample volume (m^3)	Organisms/m^3
B-1 and B-2	Inlet	0.180	761,426
	Control discharge	3.0	120,364
B-3 and B-4	Inlet	0.180	328,878
	Control discharge	3.0	63,312
B-5	Inlet	0.184	456,417
	Control discharge	3.0	149,173
B-6	Inlet	0.120	568,106
	Control discharge	3.0	54,247
B-7 and B-8	Inlet	0.186	233,601
	Control discharge	3.0	47,288
F-1	Inlet	0.179	364,467
	Control discharge	3.0	146,266
F-2 and F-3	Inlet	0.180	440,843
	Control discharge	3.0	234,890
F-4 and F-5	Inlet	0.180	233,983
	Control discharge	3.0	136,133
Require-ments	Inlet*	-	≥100,000
	Control discharge*	≥3	≥100

* Minimum criteria for live organism densities according to the IMO G8 guidelines /2/ and the ETV protocol /5/

10.1.2.2 Organism size class ≥10 and <50 µm

The average densities of viable organisms ≥10 and <50 µm in the inlet water determined by inverted microscopy varied from approx. 1,100 to 2,100 organisms/mL in the brackish water test cycles and from approx. 5,100 to 6,100 organisms/mL in the freshwater test cycles (Table 10.4). In the control discharge water, the average densities of viable organisms ranged from approx. 82 to 1,100 organisms/mL in the brackish water test cycles and from approx. 860 to 1,800 organisms/mL in the fresh water test cycles.

In test cycles B-1/B-2 and B-6, the number of live organisms in the control discharge was less than 100 organisms/mL 82 (B-6) and 98 (B-1/B-2), respectively. Grazing by zooplankton (≥50 µm) is considered to be the reason for the observed density of organisms between ≥10 µm and <50 µm (mainly algae), which attained a level below the required 100 organisms/mL. The control discharge water contained 1,147 (B-6) and 146 (B-2/B-3) organisms/mL when determined by the re-growth assay. Furthermore, the control discharge water contained 54,247 (B6) and 120,364 (B-1/B-2) organisms ≥50 µm (zooplankton) per m^3 (Table 10.3) confirming a high density of live organisms. The low density of viable organisms in the size class ≥10 and <50 µm in test cycle B-1/B-2 and B-6 is thus considered without influence on the results.

As determined by the algal re-growth assay, the average densities of organisms in the inlet water with re-growth potential ranged from approx. 2,400 to >16,000 organisms/mL in the brackish water test cycles and from approx. 7,300 to 10,200 organisms/mL in the freshwater test cycles (Table 10.4). Determined by the algal re-growth assay, the average densities of organisms in the control discharge water ranged from approx. 146 to 1,147 organisms/mL in the brackish water test cycles and from approx. 1,247 to >1,600 organisms/mL in the freshwater test cycles.

The algal phyla and species capable of growing under the conditions applied in the algal re-growth assay represented 75-100% (brackish water test cycles) and 63-71% (freshwater test cycles) of the identified phyla and species in the inlet water (Table 10.4). An overview of the algal phyla and species identified in inlet water in the BE test cycles and their ability to grow under the conditions in the re-growth assay is available in Appendix E, Table E.11.

Table 10.4 Inlet and control discharge water. Average concentrations (three replicates) of viable organisms in the size class ≥10 µm and <50 µm by microscopic counting and MPN together with measurements of primary production.

Test cycle	Sample	Microscopy (organisms/mL)	Algal re-growth (organisms/mL)	Algal re-growth (%)***	Primary production (DPM)
B-1 and B-2	Inlet	1,612	2,400	100	2,302
	Control discharge	96*	146		42
B-3 and B-4	Inlet	1,792	8,300	88	8,402
	Control discharge	138	540		107
B-5	Inlet	2,140	>16,000	92	9,416
	Control discharge	1,128	667		572
B-6	Inlet	1,107	8,933	78	7,331
	Control discharge	82*	1,147		531
B-7 and B-8	Inlet	1,346	10,200	75	8,172
	Control discharge	276	217		429
F-1	Inlet	6,105	7,300	71	9,119
	Control discharge	1,838	>1,600		3,279
F-2 and F-3	Inlet	5,572	10,200	64	5,335
	Control discharge	1,006	1,600		1,498
F-4 and F-5	Inlet	5,190	9,567	63	6,119
	Control discharge	860	1,247		1,171
Require-ments	Inlet**	≥1,000	-	-	-
	Control discharge*	≥100	-	-	-

* Grassing by zooplankton (≥50 µm) is considered to be the reason for the observed density of organisms between ≥10 µm and <50 µm (mainly algae), which attained a level below the required 100 organisms/mL. The control discharge water contained >50,000 organisms ≥50 µm (zooplankton) per m^3 (Table 10.3) confirming a high density of live organisms.

** Minimum criteria for live organism densities according to the IMO G8 guidelines /2/ and the ETV protocol /5/

*** Algal phyla and species confirmed able to grow under the conditions in the re-growth assay (per cent of the phyla and species identified in the inlet water of the respective test cycles; data from Table E.11).

DPM Disintegrations per minute

10.1.2.3 Organism size class <10 µm (bacteria)

The average densities of viable organisms <10 µm in the inlet and control discharge water are summarized in Table 10.5. In the inlet water, heterotrophic bacteria were present in concentrations from approx. 32,800 to 67,900 CFU/mL in the brackish water test cycles and from approx. 25,700 to 60,300 CFU/mL in the freshwater test cycles. In the control discharge water, heterotrophic bacteria were present in concentrations from approx. 152,100 to >200,000 CFU/mL in the brackish water test cycles and from approx. 29,300 to 59,700 CFU/mL in the freshwater test cycles.

Table 10.5 Inlet and control discharge water. Average bacterial concentrations (three replicates).

Test cycle	Sample	Heterotrophic bacteria (CFU/mL)	Enterococci (CFU/100 mL)	*E. coli* (CFU/100 mL)	*Vibrio cholerae* (CFU/100 mL)
B-1 and B-2	Inlet	67,967	150	33	-
	Control discharge	>200,000	22	<10	Absent
B-3 and B-4	Inlet	124,033	316	384	-
	Control discharge	>200,000	8.8	<10	Absent
B-5	Inlet	32,883	48	13	-
	Control discharge	>200,000	10	<10	Absent
B-6	Inlet	34,083	90	<10	-
	Control discharge	>200,000	2.5	<10	Absent
B-7 and B-8	Inlet	35,150	59	36	-
	Control discharge	152,167	17	<10	Absent
F-1	Inlet	56,733	3.3	1.2	-
	Control discharge	35,000	7.2	<1.0	Absent
F-2 and F-3	Inlet	25,700	10	17	-
	Control discharge	29,333	24	2.0	Absent
F-4 and F-5)	Inlet	60,383	17	26	-
	Control discharge	59,783	8.8	<1.0	Absent
Require-ments	Inlet*	≥10,000/ ≥1,000	-	-	-
	Control discharge*	≥1,000/≥500	-	-	-

* Minimum criteria for live organism densities according to the IMO G8 guidelines /2/ and the ETV protocol /5/

CFU Colony-forming units

10.2 Treated water

10.2.1 Physical-chemical parameters

The physical-chemical conditions of the treated water for all 13 BE test cycles are summarized in Table 10.6 and Table 10.7. Detailed data on TSS, POC, DOC, MM and UV-T are available in Appendix E. Detailed online measurement data are available in the data logging in Appendix C.

Table 10.6 Treated water. Average concentrations (three replicates) of total suspended solids (TSS), particulate organic carbon (POC), dissolved organic carbon (DOC) and mineral materials (MM).

Test cycle	Sample*	TSS (mg/L)	POC (mg/L)	DOC (mg/L)	MM (mg/L)**
B-1	Treated T0	57	-	-	-
	Treated discharge	12	7.7	4.1	4.3
B-2	Treated T0	56	-	-	-
	Treated discharge	11	1.3	3.7	10
B-3	Treated T0	49	-	-	-
	Treated discharge	11	<0.10	3.4	11
B-4	Treated T0	46	-	-	-
	Treated discharge	12	0.10	3.5	12
B-5	Treated T0	52	-	-	-
	Treated discharge	6.3	0.45	2.9	5.8
B-6	Treated T0	56	-	-	-
	Treated discharge	9.0	0.65	5.1	8.4
B-7	Treated T0	55	-	-	-
	Treated discharge	5.5	2.1	6.9	3.4
B-8	Treated T0	55	-	-	-
	Treated discharge	6.0	1.0	6.3	5.0
F-1	Treated T0	55	-	-	-
	Treated discharge	20	2.4	8.3	17
F-2	Treated T0	51	-	-	-
	Treated discharge	19	0.39	5.2	19
F-3	Treated T0	52	-	-	-
	Treated discharge	21	0.85	5.3	20
F-4	Treated T0	55	-	-	-
	Treated discharge	22	1.0	7.6	21
F-5	Treated T0	55	-	-	-
	Treated discharge	20	0.91	7.7	19

* Treated T0 samples were collected on day 0 after 1st treatment. Treated discharge samples were collected at discharge after 2nd treatment

** MM determined as the difference between TSS and POC as described in Section 5.4.6.1 of the ETV protocol /5/

Table 10.7 Treated water. Average measurements of dissolved oxygen, pH, salinity, temperature and turbidity.

Test cycle	Sample	Oxygen (%)	pH	Salinity (PSU)	Temp. (°C)	Turbidity (NTU)
B-1	Inlet	110	7.8	19	8.0	31
	Treated T0	110	8.0	19	8.2	37
	Before treatment T5	86	7.7	19	8.8	11
	Treated discharge	87	7.8	19	8.9	10
B-2	Inlet	111	7.9	19	8.3	30
	Treated T0	110	8.0	19	8.3	38
	Before treatment T5	81	7.7	19	9.5	11
	Treated discharge	83	7.7	19	9.5	10
B-3	Inlet	97	8.3	18	18	32
	Treated T0	99	8.2	18	18	31
	Before treatment T5	36	7.5	19	18	11
	Treated discharge	39	7.6	18	19	13
B-4	Inlet	98	8.3	18	18	32
	Treated T0	99	8.2	18	18	32
	Before treatment T5	32	7.5	19	19	13
	Treated discharge	35	7.6	18	19	13
B-5	Inlet	96	8.0	18	17	40
	Treated T0	98	8.0	17	17	42
	Before treatment T5	26	7.4	18	16	6.3
	Treated discharge	29	7.5	17	16	7.6
B-6	Inlet	97	7.9	17	19	39
	Treated T0	99	7.9	17	19	40
	Before treatment T5	48	7.6	17	19	8.4
	Treated discharge	50	7.6	17	19	10
B-7	Inlet	98	8.0	18	19	39
	Treated T0	99	7.9	18	19	38
	Before treatment T5	67	7.7	18	21	6.2
	Treated discharge	68	7.7	18	22	7.0
B-8	Inlet	97	8.0	18	19	40
	Treated T0	99	7.9	18	19	38
	Before treatment T5	62	7.7	18	22	6.4
	Treated discharge	64	7.6	18	22	5.5
F-1	Inlet	105	8.0	0.37	9.7	34
	Treated T0	106	8.1	0.36	9.8	30
	Before treatment T5	100	7.9	0.37	12	16
	Treated discharge	101	8.0	0.37	12	17
F-2	Inlet	91	8.2	0.37	13	31
	Treated T0	92	8.1	0.37	14	29
	Before treatment T5	97	7.8	0.12	17	131*
	Treated discharge	88	8.1	0.38	15	18

Test cycle	Sample	Oxygen (%)	pH	Salinity (PSU)	Temp. (°C)	Turbidity (NTU)
F-3	Inlet	91	8.2	0.37	13	31
	Treated T0	93	8.1	0.37	14	30
	Before treatment T5	87	8.3	0.38	15	16
	Treated discharge	90	8.1	0.37	15	13
F-4	Inlet	100	8.2	0.41	15	39
	Treated T0	102	8.1	0.41	15	36
	Before treatment T5	90	8.4	0.42	17	21
	Treated discharge	92	8.1	0.42	17	19
F-5	Inlet	101	8.2	0.41	15	38
	Treated T0	103	8.1	0.41	15	36
	Before treatment T5	91	8.2	0.41	17	20
	Treated discharge	95	8.0	0.41	17	20

PSU Practical salinity units
NTU Nephelometric turbidity units
* Turbidity probe data logging error

10.2.2 Biological parameters

10.2.2.1 Organism size class ≥50 µm

The average numbers of viable organisms ≥50 µm in their minimum dimension in the treated water are summarized in Table 10.8. The numbers of viable organisms ≥50 µm immediately after 1st treatment ranged from approx. 53 to 1,460 organisms/m^3 in the brackish water test cycles and from approx. 49 to 279 organisms/m^3 in the freshwater test cycles (Treated T0 samples in Table 10.8).

For Trojan Marinex™ BWT 500, the numbers of viable organisms ≥50 µm at discharge were 4.0; 2.7; 5.0; 2.7; 4.3; 0.33; 3.7 and 3.0 organisms/m^3 in the brackish water test cycles and 6.7; 1.3; 0.67; 0.0 and 0.0 organisms/m^3 in the fresh water test cycles (Treated discharge samples in Table 10.8).

Table 10.8 Treated water. Total sample volumes and average numbers (three replicates) of viable organisms in the size class ≥50 µm.

Test cycle	Sample*	Total sample volume (m^3)	Organisms/m^3**
B-1	Treated T0	3	1,460
	Treated discharge	3	4.0
B-2	Treated T0	3	1,066
	Treated discharge	3	2.7
B-3	Treated T0	3	127
	Treated discharge	3	5.0
B-4	Treated T0	3	151
	Treated discharge	3	2.7
B-5	Treated T0	3	163
	Treated discharge	3	4.3
B-6	Treated T0	3	356
	Treated discharge	3	0.33
B-7	Treated T0	3	53
	Treated discharge	3	3.7
B-8	Treated T0	3	78
	Treated discharge	3	3.0
F-1	Treated T0	3	279
	Treated discharge	3	6.7
F-2	Treated T0	3	55
	Treated discharge	3	1.3
F-3	Treated T0	3	107
	Treated discharge	3	0.67
F-4	Treated T0	3	57
	Treated discharge	3	0.0
F-5	Treated T0	3	49
	Treated discharge	3	0.0
Requirements	Treated discharge	≥3	<10

* Treated T0 samples were collected on day 0 after 1st treatment. Treated discharge samples were collected at discharge after 2nd treatment.

** The entire volumes of the treated discharge samples were analysed for the counting of organisms ≥50 µm.

10.2.2.2 Organism size class ≥10 and <50 µm

Table 10.9 summarizes the concentrations of viable organisms ≥10 and <50 µm in the treated water based on three different evaluation methodologies. Measurements of primary production showed that the decrease of algal photosynthesis ranged from 64 to 91% immediately after 1st treatment in the brackish water test cycles and from approx. 56 to 74% in the freshwater test cycles. The decrease in primary production in the treated discharge water after the 2nd treatment ranged from 96 to 100% in the brackish water test cycles and from approx. 94 to 99% in the freshwater test cycles.

The quantitative evaluation of the performance after the 2nd treatment at discharge was based on:

- Microscopic counting after staining with CMFDA and FDA
- Most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll.

Compliance with the ballast water discharge standard was verified by use the total of viable organisms determined by the most probable number (MPN) obtained in the algal re-growth assay and addition of viable, CMFDA/FDA-stained motile organisms ≥10 µm and <50 µm in minimum dimension without chlorophyll.

Microscopic counting after staining with CMFDA and FDA

For Trojan Marinex™ BWT 500, the numbers of CMFDA/FDA-stained organisms ≥10 and <50 µm at discharge were 327; 328; 55; 71; 137; 48; 33 and 33 organisms/mL in the brackish water test cycles and 1,957; 564; 567; 235 and 236 organisms/mL in the freshwater test cycles (Treated discharge samples in Table 10.9).

Most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll

For Trojan Marinex™ BWT 500, the total numbers of the MPN obtained in the algal re-growth assay and the CMFDA/FDA-stained motile organisms without chlorophyll at discharge were 0.60; 0.19; 0.68; 1.5; 2.5; 0.51; 4.2 and 0.85 organisms/mL in the brackish water test cycles and 9.6; 3.5; 0.20; 0.38 and 0.38 organisms/mL in the freshwater test cycles (Treated discharge samples in Table 10.9).

Table 10.9 Treated water. Average numbers (three replicates) of viable organisms in the size class ≥10 µm and <50 µm and measurements of primary production.

Test cycle	Sample*	Microscopy after CMFDA/FDA staining (organisms/mL)		Algal re-growth (org/mL)	Algal re-growth + CMFDA/FDA-stained motile organisms without chlorophyll (organisms/mL)	Primary production***	
		Total number	Motile without chlorophyll**			DPM	% decrease
B-1	Treated T0	-	-	-	-	830	64
	Treated discharge	327	0.21	0.39	0.60	87	96
B-2	Treated T0	-	-	-	-	733	68
	Treated discharge	328	0.0	0.19	0.19	41	98
B-3	Treated T0	-	-	-	-	841	90
	Treated discharge	55	0.5	<0.18	0.68	0.0	100
B-4	Treated T0	-	-	-	-	715	92
	Treated discharge	71	1.3	<0.18	1.5	1.1	100
B-5	Treated T0	-	-	-	-	1,305	86
	Treated discharge	137	2.2	0.27	2.5	16	100
B-6	Treated T0	-	-	-	-	644	91
	Treated discharge	48	0.33	<0.18	0.51	4.4	100
B-7	Treated T0	-	-	-	-	1,459	82
	Treated discharge	33	4.0	<0.18	4.2	1.7	100
B-8	Treated T0	-	-	-	-	1,079	87
	Treated discharge	33	0.67	<0.18	0.85	0.0	100
F-1	Treated T0	-	-	-	-	3,550	61
	Treated discharge	1,957	6.7	2.9	9.6	380	96
F-2	Treated T0	-	-	-	-	1,403	74
	Treated discharge	564	3.3	0.19	3.5	293	95
F-3	Treated T0	-	-	-	-	2,321	57
	Treated discharge	567	0.0	0.20	0.20	298	94
F-4	Treated T0	-	-	-	-	1,931	68
	Treated discharge	235	0.0	0.38	0.38	78	99
F-5	Treated T0	-	-	-	-	2,069	66
	Treated discharge	236	0.0	0.38	0.38	112	98
Require-ments	Treated discharge	<10	<10	<10	<10	-	

* Treated T0 samples were collected on day 0 after 1st treatment. Treated discharge samples were collected at discharge after 2nd treatment

** The concentrations of motile organisms without chlorophyll are included in the total number of organisms

*** Primary production is expressed by the measured DPM (disintegrations per minute) and as the percentage reduction of the primary production in inlet water samples

10.2.2.3 Organism size class <10 µm (bacteria)

In the treated discharge water, the contents of *E. coli* and enterococci were consistently below the ballast water discharge standard of <100 CFU/mL and <250 CFU/mL, respectively. *Vibrio cholerae* was not identified in any of the test cycles (Table 10.10).

Table 10.10 Treated water. Average bacterial concentrations (three replicates).

Test cycle	Sample*	Heterotrophic bacteria (CFU/mL)	Enterococci (CFU/100 mL)	*E. coli* (CFU/100 mL)	*Vibrio cholerae* (CFU/100 mL)
B-1	Treated T0	717	-	-	-
	Treated discharge	5.2	<1.0	<10	Absent
B-2	Treated T0	113	-	-	-
	Treated discharge	6.3	<1.0	<10	Absent
B-3	Treated T0	77	-	-	-
	Treated discharge	65	<1.0	<10	Absent
B-4	Treated T0	43	-	-	-
	Treated discharge	46	<1.0	<10	Absent
B-5	Treated T0	2.8	-	-	-
	Treated discharge	60	1.2	<10	Absent
B-6	Treated T0	81	-	-	-
	Treated discharge	168	<1.0	<10	Absent
B-7	Treated T0	68	-	-	-
	Treated discharge	130	<1.0	<10	Absent
B-8	Treated T0	47	-	-	-
	Treated discharge	23	<1.0	<10	Absent
F-1	Treated T0	82	-	-	-
	Treated discharge	62	<1.0	<1.0	Absent
F-2	Treated T0	169	-	-	-
	Treated discharge	27	<1.0	<1.0	Absent
F-3	Treated T0	71	-	-	-
	Treated discharge	27	<1.0	<1.0	Absent
F-4	Treated T0	207	-	-	-
	Treated discharge	193	<1.0	<1.0	Absent
F-5	Treated T0	146	-	-	-
	Treated discharge	106	<1.0	<1.0	Absent
Requirements	Treated discharge	-	<100	<250	<1

* Treated T0 samples were collected on day 0 after 1st treatment. Treated discharge samples were collected at discharge after 2nd treatment

CFU Colony-forming units

11 Conclusion

Trojan Marinex™ BWT 500 successfully completed five O&M test cycles with a total processed water volume exceeding 10,000 m^3.

Table 11.1 summarizes the numbers of viable organisms in water treated by Trojan Marinex™ BWT 500 at discharge, in which the viable organisms in the ≥10 and <50 µm size class were quantified by algal re-growth and addition of motile organisms without chlorophyll. DHI considers this quantification, which is also referred to as the most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll, the best available technique to determine viable organisms in the ≥10 and <50 µm size class after UV treatment. Table 11.2 summarizes the numbers of viable organisms in the ≥10 and <50 μm size class obtained by microscopic counting after staining with CMFDA and FDA and the results of measurements of algal primary production.

Practical experience from previous land-based tests conducted by DHI indicates that UV-based BWMS are frequently unable to meet the ballast water discharge standard if the treatment performance of organisms ≥10 and <50 μm is evaluated solely on the basis of microscopy after staining with CMFDA and FDA. These stains react with non-specific esterases and intact stained cells fluoresce under the microscope. The unsuitability of the microscopic counting of CMFDA/FDA-stained cells for evaluation of UV effects can be explained biologically as follows: UV radiation causes damage of the cell DNA and prevents cell proliferation but the esterase enzyme activity and the cell membrane may stay intact for several days. Consequently, the total numbers of viable organisms ≥10 and <50 μm obtained by microscopic counting after CMFDA/FDA-staining, which markedly exceed the ballast water discharge standard, were disregarded in the evaluation.

Algal re-growth determined as the MPN of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll was applied in this land-based test for the evaluation of treatment performance in relation to organisms ≥10 and <50 μm (data in Table 11.1). In the land-based test of Trojan Marinex™ BWT 500, the algal phyla and species capable of growing under the conditions applied in the algal re-growth assay represented 75-100% (brackish water test cycles) and 63-71% (freshwater test cycles) of the identified phyla and species in the inlet water.

The performance evaluation based on algal re-growth and addition of motile organisms without chlorophyll for the organisms ≥10 and <50 μm (Table 11.1) leads to the conclusion that the Trojan Marinex™ BWT 500 complies with the ballast water discharge standard in all test cycles.

Table 11.1 Average numbers (three replicates) of viable organisms in treated water at discharge. Viable organisms ≥10 and <50 µm were quantified by the most probable number of proliferating algae and addition of CMFDA/FDA-stained motile organisms without chlorophyll

Test cycle	Organisms ≥50 µm per m^3	Organisms ≥10 and <50 µm per mL Algal re-growth + CMFDA/FDA-stained motile organisms	Organisms <10 µm Enterococci (CFU/100 mL)	Organisms <10 µm *E. coli* (CFU/100 mL)	Organisms <10 µm *V. cholerae* (CFU/100 mL)
B-1	4.0	0.60	<1.0	<10	Absent
B-2	2.7	0.19	<1.0	<10	Absent
B-3	5.0	0.68	<1.0	<10	Absent
B-4	2.7	1.5	<1.0	<10	Absent
B-5	4.3	2.5	1.2	<10	Absent
B-6	0.33	0.51	<1.0	<10	Absent
B-7	3.7	4.2	<1.0	<10	Absent
B-8	3.0	0.85	<1.0	<10	Absent
F-1	6.7	9.6	<1.0	<1.0	Absent
F-2	1.3	3.5	<1.0	<1.0	Absent
F-3	0.67	0.20	<1.0	<1.0	Absent
F-4	0.0	0.38	<1.0	<1.0	Absent
F-5	0.0	0.38	<1.0	<1.0	Absent
Require-ments	<10	<10	<100	<250	<1

CFU Colony-forming units

Table 11.2 Average numbers (three replicates) of viable organisms ≥10 and <50 µm quantified by microscopic counting after staining with CMFDA and FDA and measurements of algal primary production

Test cycle	Organisms ≥10 and <50 µm	
	Microscopy after CMFDA/FDA staining (organisms/mL)	Primary production* (% decrease)
B-1	327	96
B-2	328	98
B-3	55	100
B-4	71	100
B-5	137	100
B-6	48	100
B-7	33	100
B-8	33	100
F-1	1,957	96
F-2	564	95
F-3	567	94
F-4	235	99
F-5	236	98

* Primary production is expressed as the percentage reduction of the primary production in inlet water samples

12 Quality assurance and quality control

The performance evaluation in land-based test facility of the Trojan Marinex™ BWT 500 BWMS was conducted in accordance with ISO 9001 by using the DHI Business Management System certified by DNV. The DHI Environmental Laboratory is accredited by DANAK, the Danish Accreditation and Metrology Fund, to perform ecotoxicological and ballast water tests in accordance with ISO 17025. The performance evaluation also complied with the conditions included in the QMP, Test Plan, QAPP and SOPs (see Appendix G). An amendment describing changes to the Test Plan was made during the performance evaluation period. The QMP, Test Plan, QAPP and amendment are included in Appendix A.

The acting classification society for the land-based performance evaluation of Trojan Marinex™ BWT 500 was DNV. DNV conducted a review of the Test Plan and QAPP /8/ and approved the documents. DNV inspected the first test and no specific comments related to the biological performance evaluation of the Trojan Marinex™ BWT 500 BWMS were received.

13 References

/1/ IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments. London. International Maritime Organization, 2004.

/2/ MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10 October 2008.

/3/ MEPC. Procedure for Approval of Ballast Water Management Systems that make use of Active Substances (G9). MEPC.169(57). Adopted 4 April 2008.

/4/ U.S. Coast Guard. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters. Federal Register, Vol. 77, No. 57, 23 March 2012.

/5/ U.S. Environmental Protection Agency, Environmental Technology Verification Program. Generic Protocol for the Verification of Ballast Water Treatment Technology (ETV protocol). EPA/600/R-10/146, September 2010.

/6/ Resolution MEPC.173(58). Adopted on 10 October 2008. Guidelines for approval of ballast water sampling (G2).

/7/ Trojan Marinex™ BWT 500 - Whole effluent toxicity (WET) tests. DHI. 2nd revision. November, 2013.

/8/ DNV. Review of Test Plan and QAPP – for performance evaluation in land-based test facility of the Trojan Marinex™ BWT 500 technology (Trojan Technologies). 2013.04.17.

APPENDIX A

QMP and Test Plan (including QAPP) with Amendment No. 1

Quality Management Plan

Biological Efficacy Performance Evaluation of Ballast Water Management Systems

DHI Denmark

Version 3.2

October 2012

Quality Management Plan

Biological Efficacy Performance Evaluation of Ballast Water Management Systems

DHI Denmark
Version 3.2

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Project Quality Management Plan Biological Efficacy Performance Evaluation of Ballast Water Management Systems DHI Denmark Version 3.2		Project No.			
Author Gitte I. Petersen		Date 2012.10.31 Approved by Torben Madsen			
3.2	QMP	Gip	TMA	TMA	2012.10.31
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Key words		Classification ☐ Open ☐ Internal ☒ Proprietary			

Distribution	No. of copies
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CONTENTS

APPENDICES

1 DEFINITIONS

Terms/Abbreviations	Definitions
Active substance	Active substance means a chemical or an organism, including a virus or a fungus, that has a general or specific action on or against nonindigenous species
Ballast water management system (BWMS)	A system which processes ballast water to kill, render harmless or remove organisms. The BWMS includes all ballast water treatment equipment and all associated control and monitoring equipment
Classification society	Independent classification society that conducts formal verification of the procedures applied in performance evaluation of BWMS
DHI Standard operating procedure (DHI SOP)	Document describing the procedures or characteristics for analyses, operations or tests Note: In-house methods may be used in the absence of a recognized standard, if they are commonly accepted for testing of BWMS or scientifically documented
Guidelines and standards	Guidelines means the IMO Guidelines for Approval of Ballast Water Management Systems (G8) (Reference /2/) and Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9) (Reference /3/) or the U.S. Coast Guard Standards (Reference /4/) and the ETV protocol (Reference /5/)
IMO convention	The International Convention for the Control and Management of Ship's Ballast Water and Sediments adopted by the International Maritime Organization (IMO) (Reference /1/)
Independent Laboratory	Independent organisation that meets the requirements in 46 CFR 159.010-3
International Maritime Organization (IMO)	United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships
Manufacturer (or client)	The manufacturer of a BWMS or related technology, or a party associated with such technologies, requesting a technology performance evaluation (sometimes referred to as vendor); the manufacturer is the party entering a Contract with DHI on the performance evaluation of the BWMS
Quality Assurance Project Plan (QAPP)	Project-specific technical document reflecting the implementation of quality assurance and quality control activities, the testing organisation, the testing conditions and analyses, and other conditions affecting the actual design and implementation of the required tests and evaluations Note: The DHI Business Management System applies Quality Assurance Plan as the equivalent term for the QAPP
Quality Management Plan (QMP)	Generic standard operating procedure within the DHI Business Management System describing the project management and quality control management structure
Services	When used in this QMP the term 'services' has the meaning described in Chapter 3
Test Plan	Project-specific technical document reflecting the specifics of the BWMS to be tested, the appointed classification society or Independent Laboratory, the selection of analytical procedures described in the QAPP, and other specific conditions related to the actual BWMS performance evaluation

U.S. Coast Guard	The U.S. Coast Guard is an organisation with the United States Department of Homeland Security. The Coast Guard is amending its regulations on ballast water management and engineering equipment by establishing a standard for the allowable concentration of living organisms in ships' ballast water discharged in waters of the United States and by establishing an approval process for BWMS

2 INTRODUCTION

The International Maritime Organization (IMO) has adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments /1/ to reduce the risk of spreading of harmful aquatic organisms and pathogens released with ballast water.

The IMO convention requires that all ships comply with specified water quality requirements (D2) before ballast water is released into the environment.

The performance evaluation of ballast water management systems (BWMS) aims at documenting compliance with the requirements stated in international guidelines, e.g.:

- Guidelines for Approval of Ballast Water Management Systems (G8) /2/
- Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9) /3/.

DHI provides services in relation to performance evaluation of maritime technologies and particularly BWMS. DHI's land-based test facility in Denmark, the DHI Maritime Technology Evaluation Facility, is located in Hundested. DHI has also a land-based test facility for performance evaluation of BWMS in Singapore.

The DHI Ballast Water Centre is a coordinating structure between DHI Denmark and DHI Singapore. DHI Ballast Water Centre is organized with a Ballast Water Facility Board including two members from the management in DHI Denmark and two members from the management in DHI Singapore. The object of the Board is to coordinate the development and marketing of services related to the performance evaluation of BWMS within the DHI Group.

The Quality Management Plan (QMP) is a generic standard operating procedure within the DHI Business Management System.

3 SERVICES

The QMP covers the services provided by DHI Denmark at the facilities below:

DHI
Agern Allé 5
DK-2970 Hørsholm
Denmark

and

DHI Maritime Technology Evaluation Facility
Færgevejen 18
DK-3390 Hundested
Denmark

The services include:

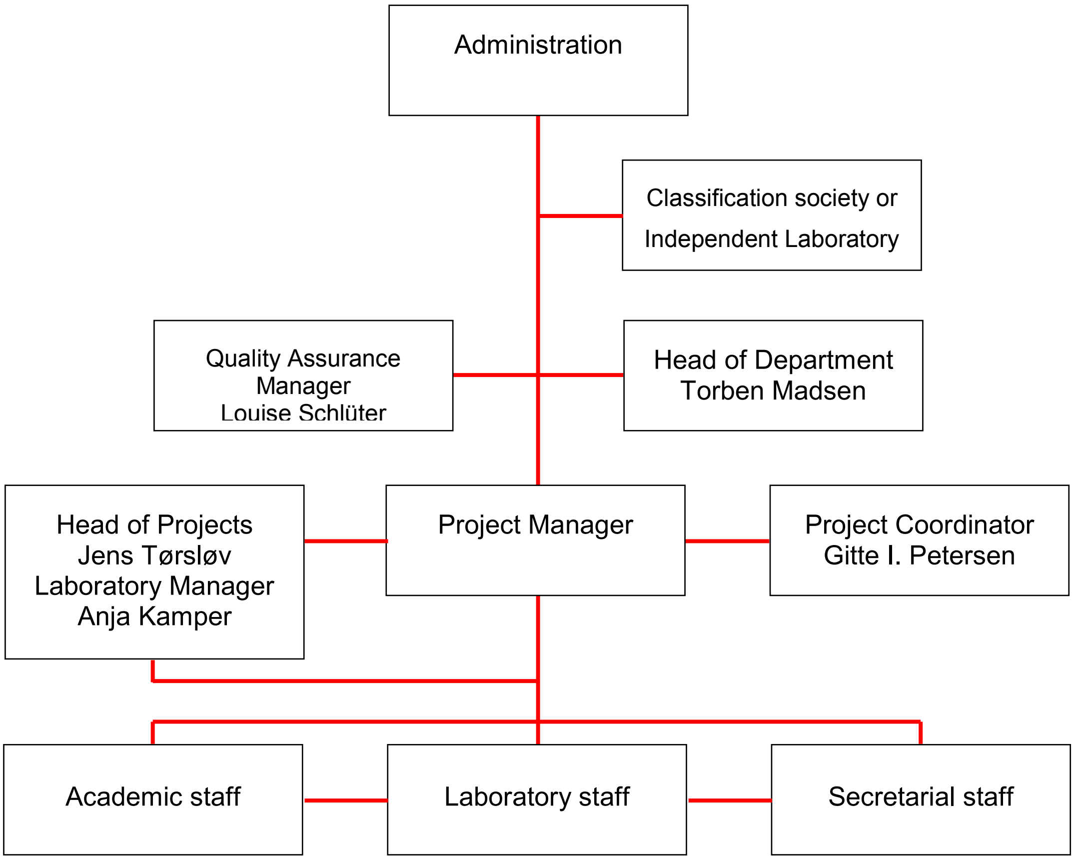
- Laboratory tests of BWMS, or ballast water treatment equipment, normally conducted at the DHI environmental laboratory in Hørsholm, Denmark, and aiming at e.g. proof-of-concept or technology optimisation prior to initiation of formal performance evaluation meeting the guidelines
- Pilot-tests of BWMS, or ballast water treatment equipment, conducted at the test facility or other facilities than a laboratory, and aiming at e.g. proof-of-concept or technology optimisation prior to initiation of formal performance evaluation meeting the guidelines
- Land-based tests of BWMS, or ballast water treatment equipment, conducted at the test facility and aiming at formal performance evaluation meeting the guidelines (e.g. type approval)
- Shipboard tests of BWMS, or ballast water treatment equipment, conducted on board vessels on which the technology is installed and aiming at formal performance evaluation meeting the guidelines (e.g. type approval).

The above activities are collectively referred to as the “services” whereas individual activities are referred to as “projects”.

The aim of the services is to provide independent, third party documentation for the performance of maritime technologies. High quality of the services is ensured through extensive quality management and use of skilled staff.

4 ORGANISATION

DHI’s project organisation is illustrated below.



4.1 Quality Assurance Manager

Senior biologist Louise Schlüter (Ph.D.) is assigned by DHI's Quality Assurance (QA) Unit as internal auditor. This includes the following tasks:

- Drafting of a plan for quality assurance
- Monitoring of compliance with the Quality Management Plan (QMP), the Quality Assurance Project Plan (QAPP), the Test Plan and the DHI standard operating procedures (DHI SOPs) by audit including the Project Manager and the laboratory staff
- Monitoring compliance with the appropriate guidelines or standards by audit including the Project Manager
- Verification of the presence of applicable staff training records
- Drafting of audit reports and verification that audit responses are appropriate and that corrective action has been implemented effectively
- Verification that the final product complies with DHIs standards for QA and, particularly, the QMP, the QAPP, the Test Plan and the guidelines and standards

4.2 Head of Department

Head of Department Torben Madsen (Ph.D.) is quality supervisor for all projects (described in the section on Services) and has the overall responsibility for the services related to performance evaluation of BWMS provided by DHI Denmark. This includes the following tasks:

- Member of the Ballast Water Test Facility Board for DHI Ballast Water Centre, a coordinating structure between DHI Denmark and DHI Singapore
- Overall responsibility for the test facility and the environmental laboratory including safe conditions of work and decisions on investments and maintenance expenses
- Overall responsibility for the liaison and contractual relations between DHI and Lloyds Register EMEA (certification of test facility), between DHI and the Danish Accreditation and Metrology Fund, DANAK (accreditation of analyses), and between DHI and the Independent Laboratory (subcontractor agreement)
- Negotiation of contracts with manufacturers (or clients)
- Appointment of Project Managers and staff responsible for quality control (QC) of individual data (data-level QC) and maintenance of staff experience records (allocation of Project Managers for specific projects is the responsibility of the Head of Projects)
- Maintenance of the QAPP and the QMP with updated versions as appropriate
- Quality control of the QAPP, Test Plan, DHI SOPs and all project proposals, deliverables and reports
- Documentation in relation to
  - Staff training and experience
  - Facilities and their maintenance
  - Records of complaints

4.3 Project Coordinator

Business Area Manager Gitte I. Petersen (Ph.D.) is responsible for the coordination, timely execution and the overall scientific quality of the services. This includes the following tasks:

- Business development and marketing
- Contact and dialogue with Lloyds Register EMEA prior to inspections and for management of the actions and documentation, in collaboration with the Laboratory Manager, as required to comply with the Certificate of Compliance issued by Lloyds Register EMEA
- Contact and dialogue with the Independent Laboratory prior to inspections and for management of the actions and documentation, in collaboration with the Laboratory Manager, as required to comply with the agreement between DHI and the Independent Laboratory
- Coordination of the services to ensure optimal logistics at the test facility, including decisions related to the practical installation of manufacturers and their technology and timing of tests
- Maintenance of the test facility including routine technical maintenance and dialogue with the Head of Department in relation to investments and maintenance expenses
- Instruction of staff with responsibility for specific tasks such as, e.g., test facility technical operations and production of test water

- Principal scientific expert with responsibility for the overall scientific quality of the services including compliance with official guidelines, standards, protocols, and requirements from classification societies and Independent Laboratories; this implies input to the QAPP and the Test Plan, revisions and implementation of DHI SOPs, and contributions to data interpretation and reporting in collaboration with the Project Manager
- Participation in discussions with the classification society or Independent Laboratory on important matters, particularly draft and final reports, together with the Project Manager

4.4 Head of Projects and Laboratory Manager

Head of Projects Jens Tørsløv (Ph.D.) has the overall responsibility for allocation of staff, planning and project execution in coordination with the Project Coordinator or the Project Manager as appropriate.

Laboratory Manager Anja Kamper (M.Sc.) allocates laboratory technicians for a specific project as part of the laboratory capacity planning by allocation of responsibility from the Head of Projects. Furthermore, the Laboratory Manager appoints one or more test co-ordinators among the laboratory technicians or the academic staff for on-site coordination of land-based test cycles.

The Laboratory Manager is responsible for the contact and dialogue with DANAK prior to inspections and for management of the actions and documentation as required to comply with the ISO 17025 accreditation.

4.5 Project Manager

The **Project Manager** is responsible for the management and efficient performance of the project in accordance with the Contract between the manufacturer and DHI, the QMP, the QAPP and the Test Plan.

The Project Manager’s tasks include:

- Organisation and management of the project
- Meetings and other communication with the manufacturer to ensure that all necessary information is available in due time
- Preparation of the draft and final Test Plan with detailed description of the project, including time schedule of activities and deliverables; the QAPP and the Test Plan shall be made available to all staff participating in the project
- Facilitation of the process for comments and responses to the QAPP and the draft Test Plan in dialogue with the manufacturer and the classification society or the Independent Laboratory
- Preparation of amendments and deviations to the Test Plan
- Communication of the project time schedule to the classification society or the Independent Laboratory to enable external audit
- Participation in discussions with the classification society or the Independent Laboratory on important matters, particularly draft and final reports, together with the Project Coordinator

- Coordination and dialogue with the Laboratory Manager in relation to the practical organisation of work involving laboratory technicians; the Project Manager shall in due time inform the Laboratory Manager on the types of tests and the required capacity to enable laboratory capacity planning
- Contracts with subcontractors (e.g. chemical analytical laboratory) as appropriate for meeting the project deliverables
- Approval of initiation of the test cycles and interruption of test cycles, e.g. in case of irregularity
- Preparation of reports

4.6 Academic staff, laboratory staff and secretaries

The tasks of the academic staff, the laboratory staff and the secretaries include:

- Maintenance of materials and equipment
- Test facility technical operations
- Test coordinator function, i.e. coordination and keeping timely records of the activities at the test facility during land-based tests
- Production of test water and monitoring of test water quality
- Sampling at the test facility
- Analysis and data processing, including data-level QC
- Contributions to test reports
- Archiving of documents and raw data
- Contributions to QAPPs, Test Plans and DHI SOPs

4.7 Manufacturer

The tasks of the representative of the manufacturer include:

- Signing a Contract with DHI for the BWMS performance evaluation project
- Project management of the manufacturers activities in the project, including the liaison with DHI and decisions in relation to the testing
- Review and comments to the draft Test Plan and approval of the final Test Plan
- Collaboration with DHI to establish all necessary arrangements prior to initiation of the test
- Review and comments to draft test reports
- Analysis and data processing, including data-level QC
- Dismantling and removal of the BWMS from the test facility after ended testing

5 TRAINING

The Quality Assurance Manager verifies the presence of appropriate training records for staff participating in performance evaluation of BWMS (Section 4.1). The Head of Department is responsible for the appointment of specific staff and documentation of training and experience records for the staff conducting the operations, sampling, analyses, data-interpretation and reporting in relation to performance evaluation of BWMS. Staff without experience in the tasks required for the performance evaluation of BWMS receives appropriate training by a peer with documented experience in the relevant tasks before participation in the testing of BWMS. Approval of staff after completed training is the responsibility of the Head of Department who appoints Project Managers and staff responsible for QC (Section 4.2), and the Laboratory Manager who appoints laboratory technicians and test coordinators for specific tasks (see Section 4.4). Laboratory technicians (and academic staff conducting analyses) must demonstrate the required skills at least once per year by use of the data quality indicators in the relevant DHI SOPs.

For performance evaluation projects, where the equipment shall be operated by DHI, the manufacturer is required to provide training of the DHI staff prior to the start of testing. DHI documents the training with a statement, signed by the manufacturer, describing the names of DHI staff who have received the training and, if appropriate, confirms that this staff have achieved the skills to train other DHI staff members.

6 PERFORMANCE OF PROJECT

6.1 Contract

A Contract between the manufacturer and DHI is negotiated and signed according to the DHI manual for project management.

6.2 Quality Assurance Project Plan

The QAPP corresponds to the Quality Assurance Plan in the DHI Business Management System. The QAPP is a project-specific technical document reflecting the implementation of quality assurance and quality control activities, the testing organisation, the testing conditions and analyses, and other conditions affecting the actual design and implementation of the required tests and evaluations.

The performance evaluation of the BWMS is described by the QAPP together with the specific details provided in the Test Plan. A QAPP (and a Test Plan) are required for performance evaluation of BWMS in land-based or shipboard tests conducted according to international guidelines and standards, but these documents may be applied for any study where a formal study protocol is needed.

6.3 Test Plan

The Test Plan is a project specific technical document reflecting the specifics of the BWMS to be tested, the appointed classification society or Independent Laboratory, the selection of analytical procedures described in the QAPP, and other specific conditions related to the actual BWMS performance evaluation

The Test Plan is

- Prepared by the project manager
- Signed by the Project Manager and the Head of Department (quality supervisor)

- Forwarded to the classification society or Independent Laboratory for review and comments
- Forwarded to the manufacturer for review, acceptance and signature.

The Test Plan typically includes the following titles:

1. Project description and treatment performance objectives
2. Project organisation and personnel responsibilities
3. Description of testing laboratory
4. Description of ballast water management system
5. Experimental design
6. Sampling and analysis plan
7. Data management, analyses and reporting
8. Amendments and deviations
9. Land-based (or shipboard) testing requirements
11. Time schedule
12. References

Amendments and deviations to the Test Plan are approved and signed by the Project Manager. Amendments describe planned changes whereas deviations describe unplanned changes to the Test Plan.

6.4 Services

The project will be conducted as described in the QAPP and the Test Plan with subsequent amendments and deviations or, alternatively, as described in the Contract between the manufacturer and DHI.

6.4.1 Laboratory tests

Laboratory tests can be initiated when the technology is ready for testing and DHI's deliverables are defined. Initiation of testing is decided by the Project Manager in agreement with the manufacturer.

6.4.2 Pilot tests

Pilot tests can be initiated when the technology is installed and ready for operation. Initiation of testing is decided by the Project Manager in agreement with the manufacturer.

6.4.3 Land-based tests

Land-based tests can be initiated when the technology, typically a fully integrated BWMS, is installed and ready for operation. Initiation of testing is decided by the Project Manager in agreement with the manufacturer.

The Project Manager decides when a test cycle in the land-based test is completed and valid, when appropriate by reference to the IMO G8 or G9 guidelines /2; 3/, US standards /4; 5/ or other standards. If required, the Project Manager can decide to interrupt a test cycle due to technical malfunctioning of the test facility or the technology, insufficient state of biological or physical parameters or for other reasons related to the quality of the test water.

6.4.4 Shipboard tests

Shipboard testing can be initiated when the technology, typically a fully integrated BWMS, is installed on the vessel and ready for operation. Initiation of testing is decided by the Project Manager in agreement with the manufacturer.

The Project Manager decides when a test cycle in the shipboard test is completed and valid by reference to the IMO G8 guidelines /2/ or, if appropriate, to US standards /4; 5/. If required, the Project Manager can decide to interrupt a test cycle due to technical malfunctioning of the technology, insufficient state of biological or physical parameters or for other reasons related to the water quality.

6.5 Reports

Reports are prepared with the details, format and language described in the Contract between the manufacturer and DHI.

6.5.1 Performance evaluation of BWMS aiming at type approval

For land-based or shipboard tests of BWMS conducted as part of the type approval process (e.g. under the IMO convention or U.S. Coast Guard Standards), the report shall include all relevant technical and analytical data and will typically contain the following items:

- Name of the manufacturer
- Executive summary
- Introduction (including a description of the test facility)
- Experimental design (including the dates for initiation and completion of tests or test cycles and procedures stated in the QAPP and the Test Plan)
- Results (presented in summarizing tables and as raw data)
- Description of the BWMS (provided by the manufacturer)
- The signed QMP, QAPP and Test Plan with all amendments and deviations

The report shall be signed by the Project Manager and the Head of Projects.

The final report will be prepared in English and forwarded to the manufacturer.

7 QUALITY MANAGEMENT PROCESSES

7.1 Quality assurance

The services are conducted in accordance with the principles of ISO 9001 by using the DHI Business Management System and the procedures in the QMP. The DHI Business Management System is found compliant with ISO 9001 as part of the ISO 17025 accreditation of the DHI Environmental Laboratory.

The DHI Quality Manager is responsible for assigning a trained internal auditor from DHI's Quality Assurance Unit to each project in accordance with the procedures for internal audit in the DHI Business Management System (section on Quality). The internal auditor shall not be involved in solving the specific project or in any project deliverables.

The DHI Business Management System (section on Quality; Internal Audit) describes procedures for audit and evaluation and the process of periodic internal auditing of projects and activities including audit responsibilities and planning, auditor training and competences and audit reporting.

The DHI Business Management System (section on Quality; Correction and Prevention) describes procedures for corrective actions, i.e. how deviations identified during operation and auditing are corrected and how future occurrence of the same deviations is prevented (preventive actions).

7.2 Document and record control

The DHI Business Management System (section on Quality; Documents and Records) includes a procedure describing the process of drafting, revising and approving documentation.

The DHI Business Management System (section on Quality/ Laboratory Analysis/ Testing and Products with reference to DHI SOPs 30/921 and 30/937) describes how records of the test are stored, transferred, maintained and controlled in order to ensure data integrity for a period defined in the QAPP, but not shorter than five (5) years after issue of the final report.

7.3 Subcontractor management

The DHI Business Management System (Section on Consulting / Administration / Contracting) describes how it is ensured that subcontractors follow quality requirements.

In addition, analytical laboratories providing analyses of any kind should:

- Maintain an ISO 17025 accreditation with the quality management system required herein.
- Apply accredited analytical methods when available.
- Apply other methods according to either international standard methods or in-house methods that are in all cases validated as required for accredited methods.

DHI SOP 30/700 furthermore describes how it is ensured that purchased items such as chemicals and glassware are controlled, accepted and calibrated.

7.4 Staff competence management

The DHI Business Management System (section on Human Resources; Development) describes how it is ensured that the projects are conducted by staff with adequate competences and knowledge. This is done by maintaining a list of functions in the test process with competence requirements and responsibilities. The list is supported by reference to staff files in the DHI CV database.

7.5 Facility management

The DHI Business Management System (Laboratory Analysis and Testing with reference to DHI SOP 30/945) describes how it is ensured that facilities and equipment are available and fit for the purposes.

7.6 Management review

The DHI Business Management System (section on Quality; Management Review) describes how the DHI management is ensuring that DHI is working according to this QMP through mechanisms such as e.g. an annual management review process.

The Quality Manager is responsible for maintenance and development of the quality system and for the internal auditing of all aspects of the system – with daily reference to the Director, Group R&D and Quality Management. The DHI Business Management System contains rules for reviews of the quality system.

7.7 Complaint management

The DHI Business Management System (section on Customer Satisfaction) describes how complaints are recorded, resolved and reported. If not resolved, complaints are handled according to the Contract between the manufacturer and DHI.

8 REFERENCES

/1/ IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments. London. International Maritime Organization, 2004.

/2/ MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10th October 2008.

/3/ MEPC. Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9). Resolution MEPC.126(53) Adopted 22nd July 2005.

/4/ U.S. Coast Guard. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters. Federal Register, Vol. 77, No. 57, March 23, 2012.

/5/ U.S. Environmental Protection Agency, Environmental Technology Verification Program. Generic Protocol for the Verification of Ballast Water Treatment Technology. EPA/600/R-10/146, September 2010.

A P P E N D I X A

BMWS testing-specific Standard Operating Procedures (DHI SOPs)

SUBJECT/SUBSUBJECT	DHI SOP NO.
ANALYTICAL METHOD DETERMINATION OF VIABLE ORGANISMS ≥50 µm	30/1700
ANALYTICAL METHOD DETERMINATION OF VIABLE ORGANISMS ≥10 µm AND < 50 µm	30/1701
ANALYTICAL METHOD DETERMINATION OF PRIMARY PRODUCTION OF MICROALGAE	30/1702
ANALYTICAL METHOD DETERMINATION OF VIABLE ALGAE BY RE-GROWTH ASSAY	30/1704
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL NUMBER OF BACTERIA BY EPIFLUORESCENCE MICROSCOPY	30/1705
MICROBIOLOGICAL TESTS DETERMINATION OF HETEROTROPHIC PLATE COUNT	30/1706
MICROBIOLOGICAL TESTS DETERMINATION OF *VIBRIO CHOLERAE* IN WATER	30/1707
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL COLIFORM, E.COLI AND ENTEROCOCCI BY Colilert*-18, Enterolert-E or Bio-Rad MUG/MUD kit	30/1708
MEASUREMENT METHOD TRO MEASUREMENT IN WATER	30/1732
HARVESTING, CULTURING AND ADDITION OF ORGANISMS	30/1734
COLLECTION OF SEAWATER	30/1735
COLLECTION OF FRESH WATER	30/1736
CRITERIA FOR TEST WATER ADDITION OF DOC, POC, MM AND BRINE	30/1737
SAMPLING PREPARATION, SUBSAMPLING AND TRANSPORTATION OF SAMPLES	30/1738
DATABASE SAMPLES, LABELS AND DATA SHEETS	30/1750
OPERATION OF THE DHI MTEF	30/1762
CLEANING RETENTION TANKS; PIPINGS AND OTHER EQUIPMENT AT TEST SITE	30/1763
MEASUREMENT METHOD ON-LINE MONITORING OF PRESSURE, TEMPERATURE, FLOW RATES AND QUALITY PARAMETERS AT TEST SITE	30/1764
MEASUREMENT METHOD FLUORESCENCE	30/1765
MEASUREMENT METHOD TURBIDITY	30/1766
DHI MTEF HEALTH AND SAFETY	30/1767
MEASUREMENT METHOD DETERMINATION OF TSS	30/1768
MEASUREMENT METHOD DETERMINATION OF DOC AND POC	30/1769
MEASUREMENT METHOD DETERMINATION OF TRANSMITTANCE	30/1770

A P P E N D I X B

Overview of lists

Overview of lists

The lists mentioned below are kept together with the rest of quality documentation.

Classification society

DHI holds a statement describing the Classification society that has certified the DHI Maritime Technology Evaluation Facility.

List of sub-contractors

DHI keeps a list of sub-contractors used during the test. The list contains information on name of company, address, contact person, e-mail, telephone number and deliveries.

List of project managers

DHI keeps a list of appointed project managers and their experience records. The project manager’s competence is documented in an available CV.

List of staff approved for functions at the test facility

DHI keeps a list of persons working at the test facility. The list contains information on the person’s activities, responsibility and documentation for training. The person’s competence is documented in an available CV.

List of Standard Operating Procedures

DHI keeps a list of DHI SOPs, including those used in relation to projects conducted at the test facility.

A P P E N D I X C

Template for amendments to QAPP

AMENDMENT

AMENDMENT NUMBER

QAPP DOCUMENT TITLE AND MONTH OF ISSUE

DATE OF AMENDMENT

DESSCRIPTION OF AMENDMENT

REASON FOR AMENDMENT

IMPACT OF AMMENDMENT

PREVENTATIVE ACTION

If relevant, action to prevent that the same cause of amendment will occur in the future.

SIGNED BY

____
Project Manager

Copy to be sent to the manufacturer, the classification society or Independent Laboratory and the DHI Quality Assurance Unit.

A P P E N D I X D

Template for deviations to QAPP

DEVIATION

DEVIATION NUMBER

QAPP DOCUMENT TITLE AND MONTH OF ISSUE

DATE OF DEVIATION

DESCRIPTION OF DEVIATION

REASON FOR DEVIATION

IMPACT OF DEVIATION

PREVENTIVE ACTION

If required, actions to be taken to prevent consequences of deviation

SIGNED BY

____

Project Manager

Copy to be sent to the manufacturer, the classification society or Independent Laboratory and the DHI Quality Assurance Unit.

Biological efficacy performance evaluation of Ballast Water Management System Trojan Marinex™ BWT 500 in land-based test

Test plan

Trojan Technologies

Test plan

April 2013

This report has been prepared under the DHI Business Management System certified by DNV and specifically for ballast water management system testing certified by Lloyd's Register	
Quality Management	BWMS Testing
ISO 9001	IMO Resolution MEPC.174(58) Annex part 2
Quality Management System certified according to DS/EN ISO 9001 by Det Norske Veritas, Business Assurance, Danmark A/S	Lloyd's Register

Approved by

15-04-2013

X Jens Tørsløv

Approved by

Signed by: Jens Tørsløv

Biological efficacy performance evaluation of Ballast Water Management System Trojan Marinex™ BWT 500 in land-based test

Test plan

Prepared for **Trojan Technologies**

Represented by **Andrew Daley**

DHI land-based test facility in Hundested

Project No	11814020
Classification	Confidential

Author	Gitte I. Petersen	

QC	Torben Madsen	

Contents

Figures

Tables

Appendices

1 Project description and treatment performance objectives

1.1 Background and objectives

This test plan describes the biological efficacy performance evaluation of the ballast water management system (BWMS) in a land-based test. The test plan provides the project specific details, such as the selection of water types or salinities, whereas the land-based test facility and the standard procedures and analyses are described in DHI's Quality Assurance Project Plan (QAPP) and the standard operating procedures (SOPs). The QAPP is provided in Appendix A.

Trojan Technologies, manufacturer of the BWMS Trojan Marinex ™ BWT 500 has entered a contract with DHI on the biological efficacy performance evaluation of the BWMS in a land-based test.

The mailing address of Trojan Technologies is:

Trojan Technologies
London, Ontario N5V 4T7
Canada

The purpose of the performance evaluation is to assure that the BWMS is capable of meeting the ballast water discharge standard in Regulation D-2 /1/, which is also known as the IMO D-2 standard. The land-based test will be conducted in accordance with Resolution MEPC.174(58) /2/ and the U.S. Coast Guard Standards /3/.

The requirements of the IMO D-2 standard and the U.S. Coast Guard ballast water discharge standard are identical.

1.2 Testing laboratory

The project is conducted by DHI Denmark (www.dhigroup.com) with the following facilities:

Mailing address:

DHI
Agern Allé 5
DK-2970 Hørsholm
Denmark
Att. Torben Madsen

DHI Maritime Technology Evaluation Facility
Færgevejen
DK-3390 Hundested
Denmark

1.3 Classification society

The classification society appointed by the manufacturer for inspection and certification of the project is:

Det Norske Veritas A/S (DNV)
Veritasveien 1
NO-1363 Høvik
Norway

2 Project organisation and personnel responsibilities

DHI's project manager for the present BWMS performance evaluation is:

Gitte I. Petersen, Senior biologist, Ph.D.

DHI's project organisation is illustrated in Figure 2.1.

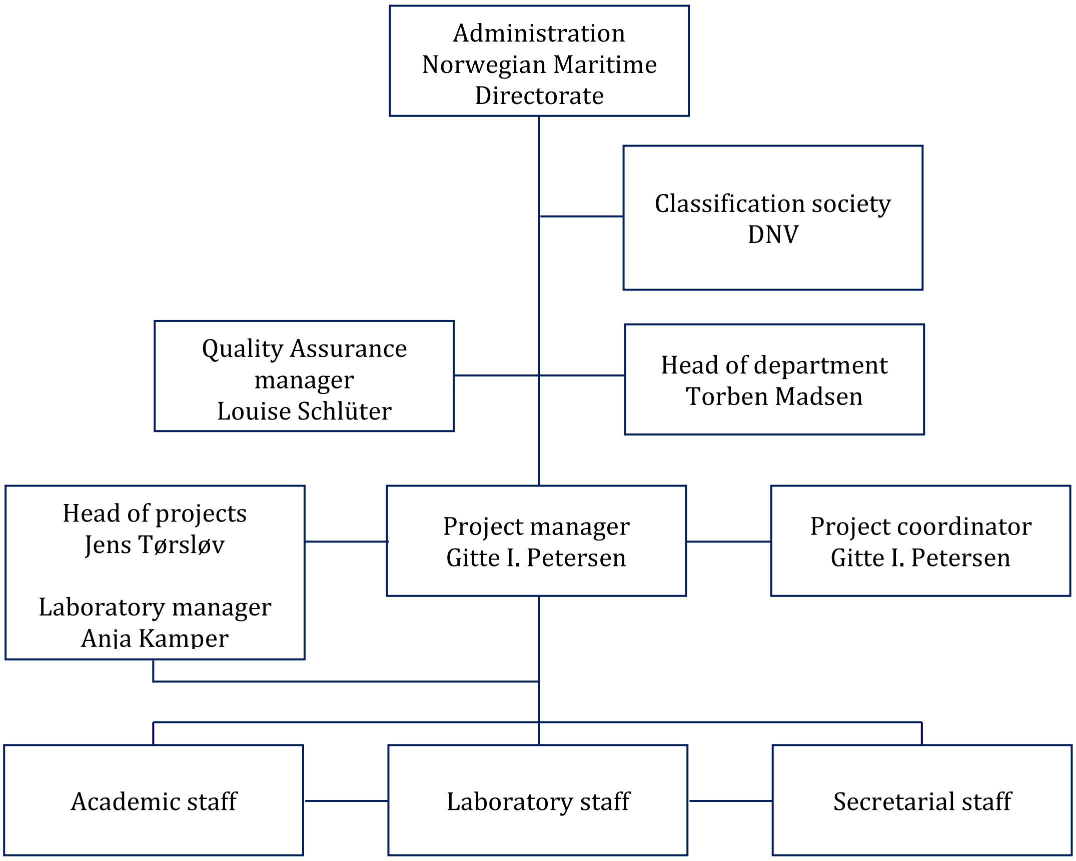


Figure 2.1 DHI's project organisation

A detailed description of the project organisation and the personnel responsibilities is provided in the QAPP.

3 Description of testing laboratory

A detailed description of the testing laboratory, including DHI Denmark, DHI Environmental Laboratory, DHI Maritime Technology Evaluation Facility and subcontractors, is provided in the QAPP.

4 Description of ballast water management system

4.1 Technology performance claims

Trojan Technologies states that the BWMS meets the following treatment and operation standards (with reference to the information required in the ETV protocol /4/, Section 3.2):

- The BWMS is designed to meet the ballast water discharge standard in IMO G8 /2/ and U.S. Coast Guard Standards /3/, §151.2030, which should be supported by quantitative measures of biological treatment efficacy expressed as a concentration upon discharge of the specified organism size classes.
- The biological treatment efficacy stated above can be achieved by the following quantitative measures of operational performance (e.g. the allowable and treatable flow rate and other relevant physical conditions):
  - Treatment rated capacity for one BWMS unit: 500 m^3/h
  - The treatment process does not need to be stopped during a filter cleaning cycle. The maritime environmental conditions, under which the BWMS can be expected to achieve the ballast water discharge standard:
    - Temperature: The BWMS works with water temperatures from -3 to 40°C (no slush or ice)
- Concentration of disinfection residuals, by-products and toxicity for relevant systems:
  - No disinfection residuals, by-products or toxicity are expected in the discharge water. Toxicity tests will be conducted to confirm this.
- The required operational and maintenance conditions (operator time, power requirements, chemical consumption requirements, reliability, etc.):
  - Please see technology and process description in Appendix B
- The projected mean time between failure for the technology given the operation and maintenance schedules provided for the technology:
  - When the given operation and maintenance schedules are adhered to, Trojan Technology does not expect failures. Projected mean times between failures cannot be estimated on the basis of the limited available experience with long-term operation.

4.2 Technology and process description

The technology and process description including the appropriate sections of the format for the Technical Data Package described in Section 3.10 of the ETV protocol /4/, with safety and environmental hazards and precautions, and photographs or drawings is enclosed in Appendix B.

4.3 Physical and electrical interfaces between the BWMS and the test facility

The BWMS will be connected to the test facility valves V20 for inlet water and V21 for treated water to retention tanks B1/B2 and/or C1/C2 (see Appendix A, QAPP, Figure 3.1). For de-ballast operations, water from retention tank B1/B2 and/or C1/C2 will be pumped to the BWMS through V20 and a separate piping section will be established for discharge of water to the harbour.

The electrical power supply to the BWMS will be delivered by the test facility generator. A cable from an onsite switchboard is connected to a socket in the BWMS. Pneumatic air is supplied to the BWMS from an external compressor.

5 Experimental design

5.1 Installation and operation of the BWMS

The manufacturer is expected to deliver the BWMS to the test facility in due time before the initiation of the performance evaluation (see Chapter 10).

The BWMS will be operated by DHI staff during all the test cycles by use of the O&M manual provided by the manufacturer as part of the Technical Data Package referred to in Chapter 4.2. The BWMS is assumed to reach a stable operating state and maintain this after no more than three start-up cycles with reference to Section 5.4.3 of the ETV protocol /4/.

To enable the independent technical operations by DHI, the manufacturer shall deliver appropriate training materials and/or practical training session(s) prior to the first test cycle.

5.2 Water types applied in the land-based test

The present land-based test will be conducted with the following water types:

Fresh water (salinity <1 PSU)
Brackish water (salinity 10-20 PSU)

The land-based test will include two (2) sets of biological efficacy (BE) test cycles, each consisting of five (5) replicate BE test cycles with a duration of at least five (5) days. Each set of BE test cycles will be conducted with test water representing one salinity range.

5.3 Biological efficacy test cycles

The BWMS will be tested at a flow rate of 500 m^3 per hour. Details on the BE test cycles and the associated operations are provided in the QAPP.

5.4 Operation and maintenance testing

O&M test will be performed as described in the QAPP.

5.5 Challenge conditions

The challenge conditions in the land-based test, including water quality characteristics and biological organism conditions, are described in the QAPP. The POC, DOC and TSS levels will follow the requirements stated in the ETV protocol /4/. Sodium citrate and/or lignin sulphonate will be used individually or in combination to adjust DOC and UVT to required/desired levels.

6 Sampling and analysis plan

6.1 Sample overview

Table 6.1 Overview of sampling and purpose of samples

Parameter	Inlet water to BWMS and control tank	Treated water (1st treatment)	Treated discharge water (2nd treatment)	Control discharge water	Sample collection	Sample volume
Ballasting operations						
Volume	×	×	×	×	Continuous	On line
Pressure	×	×	×	×	Continuous	On line
Flow	×	×	×	×	Continuous	On line
Other parameters*	×	×	×	×	Continuous	On line
Water quality conditions						
Temperature, salinity, turbidity, pH, DO**	×	×	×	×	Continuous	On line
TSS, MM, DOC***, POC*** and UV-T****	×	×	×	×	Discrete grab (3 replicates; time integrated)	Approx. 0.5 L
Concentrations of live organisms						
Viable organisms ≥50 µm/m³	×*****	×	×	×	Discrete (3 replicates; time integrated)	Inlet: 20L Discharge: 1 m³
Viable organisms ≥10 and <50 µm/mL	×	×	×	×	Discrete (3 replicates; time integrated; each representing approx. a third of the operation period)	Approx. 10 L
Viable organisms <10 µm/mL (heterotrophic aerobic bacteria, *E. coli*, enterococci and *Vibrio cholerae*)	×	×	×	×	Discrete grab (3 replicates; start, middle, end)	Approx. 0.5 L
Whole Effluent Toxicity (WET)	-	-	×******	×*****	Discrete (time integrated)	Approx. 30 L

* Operational parameters to ensure that the systems have been operated correctly and in accordance with the Operation and Maintenance manual
** Dissolved oxygen
*** Measured in inlet and discharge samples
**** UV-transmittance at 254 nm, 1 cm, measured in inlet samples
***** Collected as discrete grab samples (3 replicates; start, middle, end)
****** Only in BE test cycle No. 1. The following tests will be performed: ISO/TC 147/SC5 ISO/CD 16778 (2012). Water quality - Calanoid copepod early-life stage test with *Acartia tonsa* (5-day test); OECD TG No. 212. Fish, Short-term Toxicity Test on Embryo and sac-fry stages (10-day test)

Flow-integrated samples will be collected. The samples will be stored in thermo boxes with cooler bricks in the dark from the time of collection until handling of the samples at the DHI Environmental Laboratory.

6.2 Inlet water and treated water after first treatment

Table 6.2 Sampling and analysis of inlet water to BWMS and control tank

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Primary production (algae)	30/1702	DHI
Re-growth assay (algae)	30/1704	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1705	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
UV-transmittance at 254 nm, 1 cm	30/1770	DHI

Table 6.3 Sampling and analysis of treated water after 1st treatment

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Primary production (algae)	30/1702	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1705	DHI
Physical/chemical		
TSS	30/1768 + 30/1769	DHI
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI

6.3 Treated discharge water and control discharge water

Table 6.4 Sampling and analysis of treated discharge water after 2nd treatment

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Primary production (algae)	30/1702	DHI
Re-growth assay (algae)	30/1704	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1705	DHI
Vibrio cholerae	30/1707	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
Whole Effluent Toxicity (WET)*	30/1738	DHI

* To be performed on test cycle #1

Table 6.5 Sampling and analysis of control discharge water

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Primary production (algae)	30/1702	DHI
Re-growth assay (algae)	30/1704	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1705	DHI
Vibrio cholerae	30/1707	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
Whole Effluent Toxicity (WET)*	30/326 + 30/305 + 30/391	DHI

* To be performed on test cycle #1

7 Data management, analyses and reporting

7.1 Data management

The recording and storage of data are described in the QAPP.

7.2 Analyses

7.2.1 Organism size class ≥50 µm

Compliance with the pass criterion (Appendix A, QAPP, Chapter 10) will be verified by use of the direct count of live organisms ≥50 µm in minimum dimension.

The method for counting the live organisms ≥50 µm in minimum dimension is described in the QAPP.

7.2.2 Organism size class ≥10 µm and <50 µm

Compliance with the pass criterion (Appendix A, QAPP, Chapter 10) will be verified by use the total of viable organisms determined by measuring algal re-growth in a most probable number (MPN) assay and enumeration of viable mobile organisms ≥10 µm and <50 µm in minimum dimension that are not encompassed by the algal re-growth assay (i.e. CMFDA/FDA labelled motile organisms without chlorophyll).

The methods for counting the live organisms ≥10 and <50 µm in minimum dimension are described in the QAPP.

7.2.3 Organism size class <10 µm (bacteria)

Compliance with the pass criterion (Appendix A, QAPP, Chapter 10) will be verified by use of the colony forming units (CFU) enumerated on solid media. The methods for counting of bacteria are described in the QAPP.

7.2.4 Physical/chemical analyses

The below physical/chemical analyses will be conducted during the land-based test.

The measurements conducted at the test facility according to DHI SOPs 30/1764 and 30/1766 will include:

- pH
- Temperature
- Salinity
- Turbidity
- Dissolved oxygen
- Ballast system pressure
- Ballast system flow rates
- Water volume in retention tanks

During each ballast and de-ballast operation, the average UV intensity readings (W/m^2) displayed on the Trojan Marinex HMI-screen will be included in the DHI BE test cycle data logging procedures. The UV intensity readings will be included in relevant appendices in the final report.

Inspection of UV lamp and filter serial numbers will be performed regularly and recorded.

The analyses conducted at the DHI Environmental Laboratory will include the following measurements:

- Dissolved organic carbon (DOC)
- Particulate organic carbon (POC)
- Total suspended solids (TSS)
- UV-transmittance at 254 nm, 1 cm

7.3 Reporting

The following reports will be prepared:

- Interim BE test cycle report(s) compiling the data from BE test cycle(s)
- Draft final report compiling all relevant data from the test cycles, data interpretation and conclusion
- Final report

8 Amendments and deviations

Amendments are planned changes to the test plan. Deviations are unplanned changes. Amendments and deviations will be signed by the project manager and documented in the file and the final report.

9 Land-based testing requirements

The BWMS must comply with all requirements stated in Resolution MEPC.174(58) (/2/; Annex, Part 2, Section 2.3), and the U.S. Coast Guard Standards (/3/; §162.060-26).

Resolution MEPC.174(58), which is also referred to as the IMO G8 guidelines /2/, prescribes that the biological efficacy performance evaluation in the land-based test may be considered successful if the results of at least two sets of five (5) valid replicate test cycles, each set representing different salinity ranges, show discharge of treated ballast water in compliance with Regulation D-2 /1/ (see Appendix A, QAPP, Chapters 8-9). This means that a total of at least ten (10) successful test cycles must be conducted.

The U.S. Coast Guard Standards /3/ prescribe that the biological efficacy performance evaluation in the land-based test may be considered successful if the results of five (5) consecutive, valid test cycles show discharge of treated ballast water in compliance with the ballast water discharge standard (/3/; §151.2030), which is equivalent to Regulation D-2 /1/ (see Appendix A, QAPP, Chapters 8-9). The BWMS must be tested in the water conditions, for which it will be approved, and the approval certificate will list the salinity ranges, for which the BWMS is approved (/3/; §162.060-26(d,e)).

10 Time schedule

The testing is expected to be initiated on 2013.04.04. The following tests are expected to be performed according to the schedule given below.

Test #	Water type	Ballast	De-ballast
1+2	Brackish	2013.04.18	2013.04.23
3+4	Brackish	2013.05.02	2013.05.07
5	Freshwater	2013.05.16	2013.05.21
6+7	Freshwater	2013.05.30	2013.06.04
8+9	Freshwater	2013.06.06	2013.06.11
10	Brackish	2013.06.13	2013.06.18

The biological efficacy testing will be performed with at least one test every week or at least two tests every second week throughout the access period defined in the contract between the manufacturer and DHI, i.e. from April to June 2013.

The classification society will be updated regularly by the manufacturer or by DHI as the testing progresses.

DHI decides the applied test water salinities and the timing of the test cycles within the access period.

Dependent on weather conditions and the possibilities of preparing the right test water quality, the land-based test cycles will be conducted as outlined above.

Ballasting is performed on Thursdays from approx. 08:00 am and the de-ballasting is performed on the following Tuesday from approx. 08:00 am, if at all practicable.

A draft final report will be prepared within ten (10) weeks after successful completion of the planned test cycles.

A final report will be issued three (3) weeks after the manufacturer's approval of the draft final report.

11 References

/1/ IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments. London. International Maritime Organization, 2004.

/2/ MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10th October 2008.

/3/ U.S. Coast Guard. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters. Federal Register, Vol. 77, No. 57, March 23, 2012.

/4/ U.S. Environmental Protection Agency, Environmental Technology Verification Program. Generic Protocol for the Verification of Ballast Water Treatment Technology. EPA/600/R-10/146, September 2010.

Approval of test plan

DHI Denmark

Project management Date: 2013.04.15

Gitte I. Petersen

Quality control Date: 2013.04.15

Torben Madsen

This test plan is accepted and my signature authorizes the study to proceed as described in this document.

Manufacturer Date: 2013/04/16

Andrew Daley
Trojan Technologies

APPENDIX A

Quality Assurance Project Plan

Biological efficacy performance evaluation of Ballast Water Management Systems

Quality Assurance Project Plan

Version 2.2
March 2013

This report has been prepared under the DHI Business Management System certified by DNV and specifically for ballast water management system testing certified by Lloyd's Register	
Quality Management	BWMS Testing
ISO 9001	IMO Resolution MEPC.174(58) Annex part 2
Quality Management System certified according to DS/EN ISO 9001 by Det Norske Veritas, Business Assurance, Denmark A/S	Lloyd's Register

Approved by
18-03-2013 X Approved by Signed by: Torben Madsen

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Abbreviations

Abbreviation	Description
BE	Biological efficacy
BWMS	Ballast water management system
CFU	Colony forming units
CMFDA	Chloromethylfluorescein diacetate
DANAK	Danish Accreditation and Metrology Fund
DNV	Det Norske Veritas
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
DQI	Data quality indicators
FDA	Fluorescein diacetate
IMO	International Maritime Organization
ISPS	International Safety Port System
kVA	Kilovolt-ampere
MEPC	Marine Environment Protection Committee
MM	Mineral materials
MPN	Most probable number
O&M	Operation and maintenance
POC	Particulate organic carbon
POM	Particulate organic matter
PSU	Practical salinity units
QA	Quality assurance
QAPP	Quality Assurance Project Plan
QC	Quality control
QMP	Quality Management Plan
SOP	Standard operating procedure
TSS	Total suspended solids
WET	Whole effluent toxicity

1 Project description and treatment performance objectives

1.1 Background and objectives

For an application for final approval, the IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments /1/ requires a performance evaluation of ballast water management systems (BWMS) according to the principles laid down in Resolution MEPC.174(58) /2/, generally referred to as IMO G8 guidelines, and, for systems that make use of active substances, also Resolution MEPC.169(57) /3/, generally referred to as IMO G9 guidelines. The purpose of the performance evaluation is to assure that BWMS approved by administrations are capable of meeting the ballast water performance standard in Regulation D-2 /1/, also known as the IMO D-2 standard, in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health. The U.S. Coast Guard Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters /4/ (§151.2030) establish a ballast water discharge standard similar to the IMO D-2 standard. According to the U.S. Coast Guard the test set up in land-based test cycles of BWMS must operate as described in the ETV protocol /5/.

1.2 Testing laboratory

The project is conducted by DHI Denmark (www.dhigroup.com) with the following facilities:

Mailing address:

DHI
Agern Allé 5
DK-2970 Hørsholm
Denmark
Att. Torben Madsen

DHI Maritime Technology Evaluation Facility
Færgevejen
DK-3390 Hundested
Denmark

DHI Denmark and its facilities are described in detail in Chapter 3.

2 Project organisation and personnel responsibilities

DHI's project organisation is illustrated in Figure 2.1.

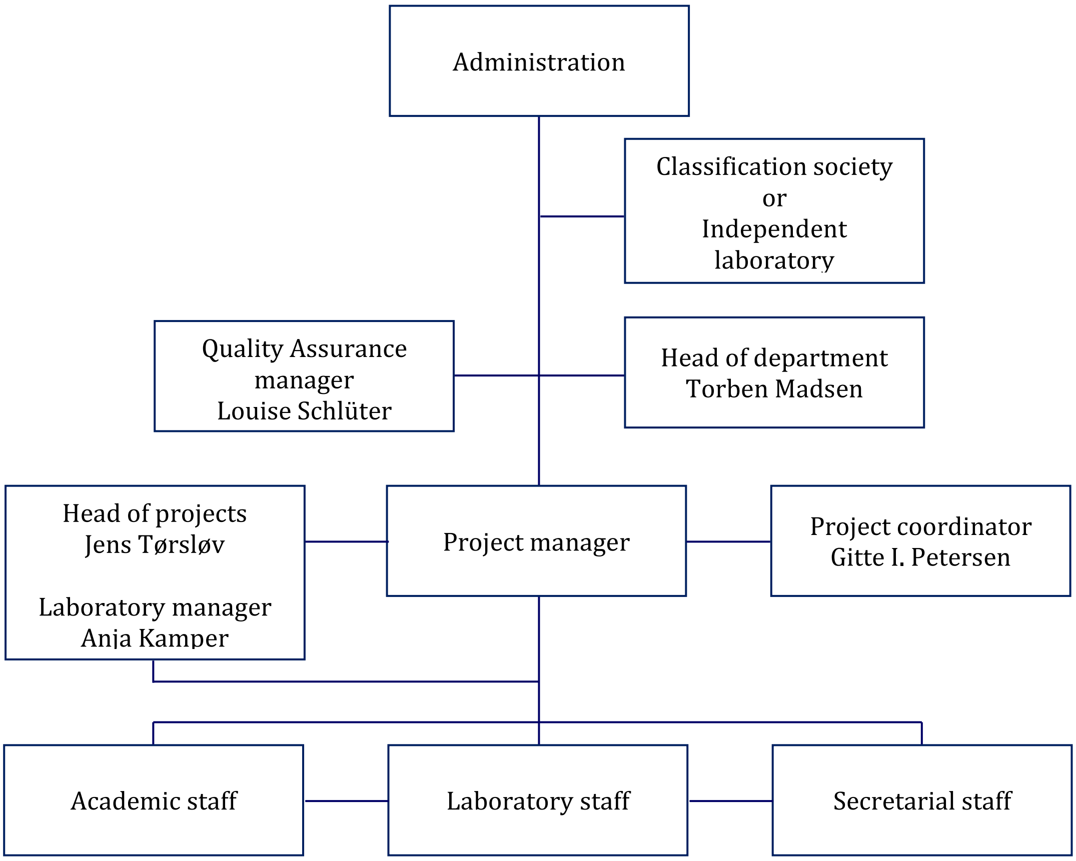


Figure 2.1 The DHI project organisation

2.1 Quality Assurance manager

Senior biologist Louise Schlüter (Ph.D.) is assigned by DHI's Quality Assurance (QA) unit as internal auditor (see Chapter 10). This includes the following tasks:

- Drafting of a plan for quality assurance
- Monitoring of compliance with the Quality Management Plan (QMP), the Quality Assurance Project Plan (QAPP), the Test Plan and the standard operating procedures (SOPs) by audit including the project manager and the laboratory staff
- Monitoring compliance with the appropriate guidelines or standards by audit including the project manager
- Verification of the presence of applicable staff training records
- Drafting of audit reports and verification that audit responses are appropriate and that corrective action has been implemented effectively
- Verification that the final product complies with DHIs standards for QA (Chapter 10) and, particularly, the QMP, the QAPP, the Test Plan and the guidelines and standards

2.2 Head of department

Head of department Torben Madsen (Ph.D.) is quality supervisor for all projects and has the overall responsibility for the services related to performance evaluation of BWMS provided by DHI Denmark. This includes the following tasks:

- Member of the Ballast Water Test Facility Board for DHI Ballast Water Centre, a coordinating structure between DHI Denmark and DHI Singapore

- Overall responsibility for the test facility and the DHI Environmental Laboratory including health and safety in the work place and decisions on investments and maintenance expenses
- Overall responsibility for the liaison and contractual relations between DHI and Lloyds Register EMEA (certification of test facility), between DHI and the Danish Accreditation and Metrology Fund, DANAK (accreditation of analyses), and between DHI and the Independent Laboratory (subcontractor agreement)
- Negotiation of contracts with manufacturers (or clients)
- Appointment of project managers and staff responsible for quality control (QC) of individual data (data-level QC) and maintenance of staff experience records (allocation of project managers for specific projects is the responsibility of the head of projects)
- Maintenance of the QAPP and the QMP /6/ with updated versions as appropriate
- Quality control of the QAPP, Test Plan, SOPs and all project proposals, deliverables and reports
- Documentation in relation to
    - Staff training and experience
    - Facilities and their maintenance
    - Records of complaints

2.3 Project coordinator

Business area manager Gitte I. Petersen (Ph.D.) is responsible for the coordination, timely execution and the overall scientific quality of the services. This includes the following tasks:

- Business development and marketing
- Contact and dialogue with Lloyds Register EMEA prior to inspections and for management of the actions and documentation, in collaboration with the laboratory manager, as required to comply with the Certificate of Compliance issued by Lloyds Register EMEA
- Contact and dialogue with the Independent Laboratory prior to inspections and for management of the actions and documentation, in collaboration with the laboratory manager, as required to comply with the agreement between DHI and the Independent Laboratory
- Coordination of the services to ensure optimal logistics at the test facility, including decisions related to the practical installation of manufacturers and their technology and timing of tests
- Maintenance of the test facility including routine technical maintenance and dialogue with the head of department in relation to investments and maintenance expenses
- Instruction of staff with responsibility for specific tasks such as test facility technical operations and production of test water
- Principal scientific expert with responsibility for the overall scientific quality of the services, including compliance with official guidelines, standards, protocols and requirements from classification societies and Independent Laboratories; this implies input to the QAPP and the Test Plan, revisions and implementation of SOPs, and contributions to data interpretation and reporting in collaboration with the project manager
- Participation in discussions with the classification society or the Independent Laboratory on important matters, particularly draft and final reports, together with the project manager

2.4 Head of projects and laboratory manager

Head of projects Jens Tørsløv (Ph.D.) has the overall responsibility for allocation of staff, planning and project execution in coordination with the project coordinator or the project manager as appropriate.

Laboratory manager Anja Kamper (M.Sc.) allocates laboratory technicians for specific projects as part of the laboratory capacity planning by allocation of responsibility from the head of projects. Furthermore, the laboratory manager appoints one or more test coordinators among the laboratory technicians or the academic staff for on-site coordination of land-based test cycles.

The laboratory manager is responsible for the contact and dialogue with DANAK prior to inspections and for management of the actions and documentation as required to comply with the ISO 17025 accreditation /7/.

2.5 Project manager

The project manager is responsible for the management and efficient performance of the project in accordance with the Contract between the manufacturer and DHI, the QMP, the QAPP and the Test Plan.

The project manager's tasks include:

- Organisation and management of the project
- Meetings and other communication with the manufacturer to ensure that all necessary information is available in due time
- Preparation of the draft and final Test Plan with detailed description of the project, including time schedule of activities and deliverables; the QAPP and the Test Plan shall be made available to all staff participating in the project
- Facilitation of the process for comments and responses to the QAPP and the draft Test Plan in dialogue with the manufacturer and the classification society or the Independent Laboratory
- Preparation of potential amendments and deviations to the Test plan
- Communication of the project time schedule to the classification society or the Independent Laboratory to enable external audit
- Participation in discussions with the classification society or the Independent Laboratory on important matters, particularly draft and final reports, together with the Project Coordinator
- Coordination and dialogue with the laboratory manager in relation to the practical organisation of work involving laboratory technicians; the project manager shall in due time inform the laboratory manager of the types of tests and the required capacity to enable laboratory capacity planning
- Contracts with subcontractors (e.g. chemical analytical laboratory) as appropriate for meeting the project deliverables
- Approval of initiation of the test cycles and interruption of test cycles, e.g. in case of irregularity
- Preparation of reports

2.6 Academic, laboratory and secretarial staff

The tasks of the academic, the laboratory and the secretarial staff include:

- Maintenance of materials and equipment
- Test facility technical operations
- Test coordinator function, i.e. coordination and keeping of timely records of the activities at the test facility during land-based tests
- Production of test water and monitoring of test water quality
- Sampling at the test facility
- Analysis and data processing, including data-level QC
- Contributions to test reports
- Archiving of documents and raw data
- Contributions to QAPPs, Test Plans and SOPs

2.7 Manufacturer

The tasks of the representative of the manufacturer include:

- Signing a Contract with DHI for the BWMS performance evaluation project
- Project management of the manufacturers activities in the project, including the liaison with DHI and decisions in relation to the testing
- Review and comments to the draft Test Plan and approval of the final Test Plan
- Collaboration with DHI to establish all necessary arrangements prior to initiation of the test
- Review and comments to draft test reports
- Dismantling and removal of the BWMS from the test facility after ended testing

3 Description of testing laboratory

3.1 DHI Denmark

DHI is an independent, international consulting and research organisation established in Denmark and today represented in all regions of the world with a total of more than 1,000 employees. Our objectives are to advance technological development, governance and competence in the fields of water, environment and health. DHI works with governmental agencies and authorities, contractors, consultants and numerous industries.

DHI has no involvement, intellectual or financial, in the mechanics, design or marketing of the products and technologies that are being evaluated. To ensure that DHI's tests are uncompromised by any real or perceived individual or team bias relative to test outcomes, DHI's test activities are subject to rigorous quality assurance (QA), quality control (QC) and documentation.

DHI's quality management system is certified according to ISO 9001 by DNV (Det Norske Veritas). The certification is facilitated by the implementation of the DHI Business Management System (see Chapter 10).

3.2 DHI Environmental Laboratory

DHI's Environmental Laboratory has an accreditation according to ISO 17025 /7/ which includes ecotoxicological studies and analyses related to the performance evaluation of BWMS. Furthermore, the laboratory is authorized to carry out ecotoxicological studies in compliance with the OECD Principles of Good Laboratory Practice (GLP) /8/.

DHI's Environmental Laboratory and staff normally analyse all samples collected during the performance evaluation of BWMS. If required, specialized chemical analyses of, e.g., active substances or disinfection by-products, are conducted by a subcontractor identified in the section on Subcontractors.

3.3 DHI Maritime Technology Evaluation Facility

DHI holds a Certificate of Compliance issued by Lloyd's Register EMEA for the performance of land-based and shipboard testing of BWMS (Appendix A).

The travel time from the DHI Maritime Technology Evaluation Facility to the DHI Environmental Laboratory is approx. 50 min, which enables analysis or treatment of the samples within 6 hours.

The test facility is used to conduct biological evaluations of maritime technologies. The test facility is covered by the International Safety Port System (ISPS). Hundested Harbour is registered at the IMO's website (Port facilities) under Port ID No. 266076DKHUN, Port facility 1651.

The test facility includes seven cylindrical tanks constructed in galvanized steel and coated with a non-toxic top coating:

- One open 750-m^3 source tank, Tank D in Figure 3.1. The source tank is equipped with a propeller, which creates a slow circulation in order to maintain the homogeneity of the test water. A bridge across the top of the source tank is established for monitoring the homogeneity.
- Six closed 250-m^3 retention tanks, Tanks A1, B1, C1, A2, B2 and C2 in Figure 3.1. Tanks A1 and A2 are also described as 'control tanks' and are used for untreated test water. Tanks B1, C1, B2 and C2 are retention tanks for treated test water. Each of the six retention tanks is equipped with a submersible agitator (with three-blade propeller) giving the possibility to create a slow circulation in order to maintain homogeneity of the test water.

The piping connecting source tank, control tanks, retention tanks, pump and BWMS is made of polyethylene. The diameters are 315 mm and 350 mm for the piping connecting the A1, B1 and C1 tanks and 400 mm and 500 mm for the piping connecting the A2, B2 and C2 tanks.

The piping system connecting the source tank and the retention tanks is equipped with sampling ports. The sampling ports are equipped with the following sample outlets:

1. Sample outlet for ≥1-m^3 samples (to be used for analysis of organisms ≥50 µm)
2. Sample outlet for ≥10-L samples (to be used for analysis of organisms ≥50 µm and organisms ≥10 to <50 µm)
3. Sample outlet for microbiology samples
4. Sample outlet for samples for analysis of dissolved organic carbon (DOC), particulate organic carbon (POC), total suspended solids (TSS) and transmittance

The test facility is equipped with sensors for automatic logging of flow, pressure, water levels, temperature, dissolved oxygen, pH, salinity and turbidity.

The test facility includes a main pump with a flow performance of 250-500 m^3/hour. By use of a harbour piping, this pump can be used to provide a continuous flow of brackish water directly from the harbour to the BWMS with a capacity of up to approx. 300 m^3/hour. Furthermore, the test facility includes electrical generator power supply up to 150 kVA.

If needed to fulfil the test water quality requirements, appropriate volumes of cultivated organisms can be added to the source tank by an auxiliary pump.

The exact configuration of the test facility piping and equipment may be subject to minor changes.

The procedures, guidelines or characteristics for analyses, operations or tests performed in the DHI Environmental Laboratory, at the test facility or on board a vessel are described in the DHI SOPs.

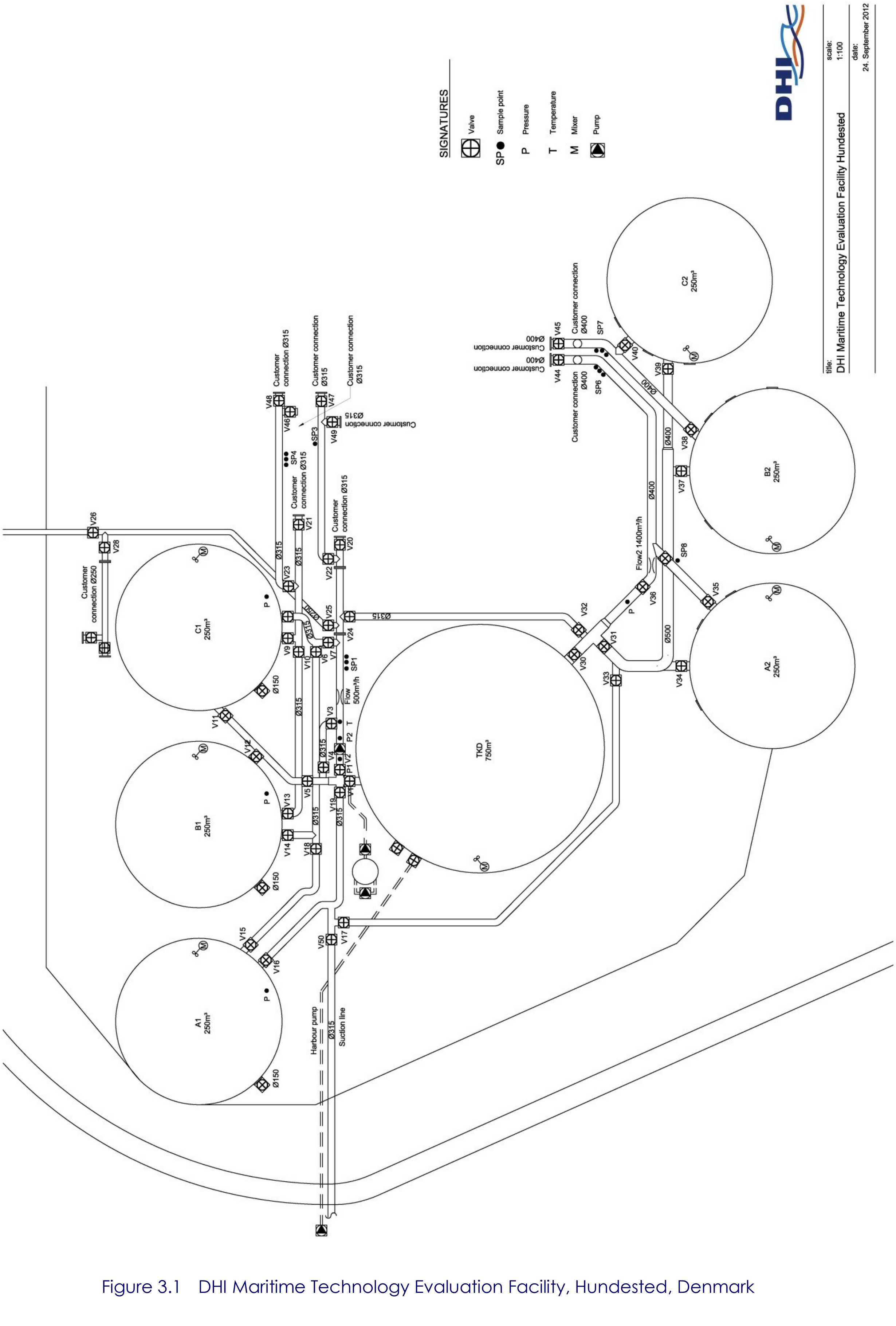


Figure 3.1 DHI Maritime Technology Evaluation Facility, Hundested, Denmark

3.4 Test facility equipment and calibration programmes

Test facility equipment used for analysis of physical-chemical and biological parameters is included in the ISO 17025 accreditation of DHI's Environmental Laboratory. The procedures and frequency for the calibration specific equipment are described in DHI SOPs, and compliance of the equipment with the DHI SOPs is inspected regularly by DANAK.

The test facility is equipped with an on-line monitoring system consisting of several sensors for monitoring of pressure, temperature, flow rate and water quality parameters (Table 3.1).

Table 3.1 Specification of sensor and monitoring equipment at the test facility

No.	Function	Location	Name	Range	Serial No.	Supplier
1	Determination of water level	Bottom of source water tank D	Klay 8000-D-S-I.	0-7.5 mwc*	10204262	Gustaf Fagerberg A/S
2	Determination of water level	Bottom of retention tank C1	Klay 8000-C-S-I.	0-5.4 mwc*	10204265	Gustaf Fagerberg A/S
3	Determination of water level	Bottom of retention tank B1	Klay 8000-C-S-I.	0-5.4 mwc*	10204264	Gustaf Fagerberg A/S
4	Determination of water level	Bottom of retention tank A1	Klay 8000-C-S-I.	0-5.4 mwc*	10204263	Gustaf Fagerberg A/S
5	Determination of water level	Bottom of retention tank C2	Klay 8000-C-S-I.	0-6.0 mwc*	10304331	Gustaf Fagerberg A/S
6	Determination of water level	Bottom of retention tank B2	Klay 8000-C-S-I.	0-6.0 mwc*	10310814	Gustaf Fagerberg A/S
7	Determination of water level	Bottom of retention tank A2	Klay 8000-D-S-I.	0-7,5 mwc*	10304330	Gustaf Fagerberg A/S
8	Determination of pressure in pipes before pump	P1	Klay 8000-E-S-I	0-3.0 bar	10204259	Gustaf Fagerberg A/S
9	Determination of pressure in pipes after pump	P2	Klay 8000-F-S-I	0-4,5 bar	10307332	Gustaf Fagerberg A/S
10	Determination of pressure in pipes after pump	P22	Klay 8000-F-S-I	0-4,5 bar	10304329	Gustaf Fagerberg A/S
11	Determination of pumping flow	Flow	Krohne DN300 Optiflux 2100C with electromagnetig flow converter (IFC100)	0-600 m^3/h	A0991632	Gustaf Fagerberg A/S
12	Determination of temperature in pipes	T	Inor RBS10 PT100 (66RBS10)	0-50°C	v033682 20101042 350120-1	Gustaf Fagerberg A/S
13	Determination of pumping flow	Flow2	Krohne DN400 Optiflux 2000 with electromagnetig flow converter (IFC100)	0-1400 m^3/h	A1094864	Gustaf Fagerberg A/S
14	Determination of pH, temperature, salinity, dissolved oxygen and turbidity before treatment and control discharge	WQ.intake: Sonde equipped with flow chamber connected at relevant sampling point	YSI 6600 V2 data sonde: • 6561 pH sensor • 6150 ROX optical dissolved oxygen sensor • 6136 turbidity sensor	n.a.	11C 101786	YSI inc.
15	Determination of pH, temperature, salinity, dissolved oxygen and turbidity after treatment	WQ.treated: Sonde equipped with flow chamber connected at relevant sampling point	YSI 6600 V2 data sonde: • 6561 pH sensor • 6150 ROX optical dissolved oxygen sensor • 6136 turbidity sensor	n.a.	11C 101787	YSI inc.

* Meter water column

All sensor signals are recorded via 3 Advantech ADAM-6024 modules. Each of these modules can accept 6 analogue input signals (user defined as 0/4-20 mA or ±10 volt), 2 digital input signals, 2 analogue outputs (user defined as 0/4-20 mA or ±10 volt), and 2 digital out-puts. Sensor readings are transferred to an industrial PC type (i-PC) Advantech UNO-2182 running Windows XP sp3. The i-PC is connected to the internet through a 3G modem Huawei B970. The measured data are transferred to an SQL-database running on the PLCSQL server. In the case that the i-PC loses connection to the database-server, the data will be buffered on the i-PC until connection is re-established. Once a day, backup of the database is performed and the backup file is stored on a RAID-5 NAS disk-array placed in another building than the server itself. The client server data management software program DIMS (developed by DHI) is used for handling and storage of the data.

Quality control of the on-line monitoring system is conducted by the activities described below.

The sensor for monitoring of the water level in the source tank (Tank D) is verified by measuring the height of the water columns at maximum and minimum water levels compared to the results from the sensor. Deviations of 3% and 5% are accepted at maximum and the minimum water levels, respectively.

The flow meter is verified by comparing the measured water levels in the tanks with the measured flow. A deviation of 8% is accepted. The control is performed after the sensors for determining the water level have been verified.

The pressure transmitters for monitoring the pressure in the piping are verified by reading the pressure at the maximum and the minimum water levels in the source tank (Tank D) with open piping between the transmitters and the source tank and with a closed valve behind the pressure transmitters. The monitored pressure is compared with the difference in water heights. Deviations of 3% and 5% are accepted at maximum and the minimum water level, respectively.

The thermo sensor is verified by comparing the recorded result with the temperature measured with a traceable thermometer in a time-equivalent flowing sample. A deviation of 1.0°C is accepted.

The water quality sensors are verified by checking the readings in the relevant standard solution. The following deviations are accepted: ±0.2 units for pH, 3% for dissolved oxygen, 5% for turbidity and 2% for conductivity. Verification of dissolved oxygen measurements can also be conducted by comparison between sensors and a calibrated dissolved oxygen meter. All of the water quality sensors require periodic calibration to assure high performance. The calibration is conducted at least every second week by use of the relevant standard solution.

Data for all relevant parameters are extracted from the on-line monitoring system and evaluated after each test cycle. The sensors are adjusted and calibrated again in case of non-compliance with the acceptance criteria.

3.5 Subcontractors

Chemical analyses:
MILANA A/S
Bakkegårdsvej 406 A
DK-3050 Humlebæk, Denmark

Microbiology; verification of *Vibrio cholerae* according to DHI SOP 30/1707:

Statens Serum Institut
Artillerivej 5
DK-2300 København S
Denmark

4 Description of ballast water management system

A complete description of the BWMS is provided in the Test Plan.

5 Performance evaluation in land-based test

5.1 Experimental design

5.1.1 Overview of test parameters

DHI's land-based test applies high quality facilities and state-of-the-art methods. A comparison of DHI's test parameters with the requirements of the IMO G8 guidelines /2/ and the ETV protocol /5/ is presented in Table 5.1.

Table 5.1 Comparison of test parameters applied by DHI and the requirements in the IMO G8 and ETV protocol

Parameter	Sub-category	IMO G8	ETV protocol	DHI
Organisms to be evaluated	Zooplankton, live organisms ≥ 50 µm in size	Naturally occurring, or cultured organisms may be added to the test water.	Ambient assemblage supplemented by the addition of standard test organisms.	Naturally occurring in the harbour outside the test facility (brackish and marine) and in Lake Arresø (fresh). For brackish and marine tests, enhanced density of natural organisms can be obtained by collection of backwash from a 10 µm mesh low pressure filter; in addition cultured organisms can be added if required.
	Protists, live organisms 10-50 µm in size	Naturally occurring, or cultured species that may be added to the test water.	Ambient assemblage supplemented by the addition of standard test organisms.	Naturally occurring in the harbour outside the test facility (brackish and marine) and in Lake Arresø (fresh). For brackish and marine tests, enhanced density of natural organisms can be obtained by collection of backwash from a 10 µm mesh low pressure filter; in addition cultured organisms can be added if required.
	Bacteria	Naturally occurring, or cultured species that may be added to the test water.	Ambient assemblage supplemented by the addition of standard test organisms.	Naturally occurring in the harbour outside the test facility (brackish and marine) and in Lake Arresø (fresh).
Intake organism diversity and density	Zooplankton, live organisms ≥ 50 µm in size	Organisms ≥50 µm in minimum dimension should be present in a total density of preferably 10^6 individuals but not less than 10^5 individuals per m^3, and should consist of at least 5 species from at least 3 different phyla/divisions.	Total concentration = minimum of 1×10^5 organisms/m^3.	Organisms ≥ 50 µm in minimum dimension are present in a total density above 10^5 live individuals per m^3 and consist of at least 5 species from at least 3 different phyla/divisions.
	Protists, live organisms C in size	Organisms ≥10 µm and less than 50 µm in minimum dimension should be present in a total density of preferably 10^4 individuals but not less than 10^3 individuals per ml, and should consist of at least 5 species	Organisms in the ≥10 µm and <50 µm size class must be present in minimum concentrations of 10^3 organisms/mL with at least 5 species across 3 phyla.	Organisms ≥10 µm and less than 50 µm in minimum visible dimension are present in a total density above 10^3 cells per mL, and consist of at least 5 species from at least 3 different phyla.

Parameter	Sub-category	IMO G8	ETV protocol	DHI
		from at least 3 different phyla/divisions.		
	Bacteria	Heterotrophic bacteria should be present in a density of at least 10^4 living bacteria per mL.	Organisms in the < 10 µm size class must be present in minimum concentrations of 10^3/mL as culturable aerobic heterotrophic bacteria.	Heterotrophic bacteria are typically present in a density of at least 10^4/mL as culturable aerobic heterotrophic bacteria.
Water quality of intake/source water	N/A	• Dissolved organic carbon (DOC): >5 mg/L; • Particulate organic carbon (POC): >5 mg/L; • Total suspended solids (TSS): >50 mg/L.	• Dissolved organic matter: min. 6 mg/L as DOC; • Particulate organic matter (POM): min. 4 mg/L as POC; • Mineral matter (MM): min. 20 mg/L; • TSS = POM + MM: min. 24 mg/L.	Dependent season and location, typical ambient values include: • DOC: 1-7 mg/L; • POC: 0-2 mg/L; • TSS: 1-20 mg/L. DOC, POC and TSS are typically adjusted to increase levels by using lignin sulphonate, maizena and kaolin, respectively.
Salinity of intake/source water	N/A	• Freshwater <3 PSU; • 10 PSU difference to brackish and marine	• Fresh <1 PSU; • Brackish 10-20 PSU; • Marine 28-36 PSU	• Fresh <1 PSU (Lake Arresø); • Brackish 15-28 PSU (harbour outside the test facility); • Marine 28-36 PSU (harbour water augmented by addition of brine)
Sample volume	Zooplankton, live organisms ≥ 50 µm in size	At least 20 L of intake water and 1 m³ of treated water.	Minimum of 3 m³ concentrated to 1,000 mL per sample.	Dependent on Test Plan: IMO G8. Inlet: At least 20 L concentrated to approx. 500 mL per sample. Treatment: Minimum 1 m³, concentrated to approx. 500 mL per sample. USCG/ETV. Inlet: Minimum 1 m³ concentrated to 500-1,000 mL Treatment: Minimum 3 m³ concentrated to 500-1,000 mL.
	Protists, live organisms ≥10-<50 µm in size	At least 1 L of intake water and 10 L of treated water.	Minimum of 3 m³ concentrated to 1,000 mL per sample.	Minimum 10 L per sample. 100-500 mL sub-sample concentrated to 20 mL on treated discharge
	Bacteria	At least 500 mL of intake water and 500 mL of treated water.	1,000 mL per sample.	At least 500 mL per sample*
Number of intake samples	Zooplankton, live organisms ≥ 50 µm in size	Minimum of 3 samples collected from the treatment track and 3 samples collected from the control track.	1 sample immediately prior to water entry to the control tank and 1 sample immediately before entry to the in-line BWMS, or (if control and challenge water are shown to be representative) one sample before the splitter.	IMO G8. 3 samples (start, middle, end). USCG/ETV. Minimum 1x1 m³ continuous time integrated concentrated to 500-1,000 mL
	Protists, live organisms ≥10-<50 µm in size	Minimum of 3 samples collected from the treatment track and 3 samples collected from the control track.	1 sample immediately prior to water entry to the control tank and 1 sample immediately before entry to the in-line BWMS, or (if control and challenge water are shown to be representative) one sample before the splitter.	3 samples (start, middle, end)
	Bacteria	Minimum of 3 samples collected from the treatment track and 3 samples collected from the control track.	1 sample immediately prior to water entry to the control tank and 1 sample immediately before entry to the in-line BWMS, or (if control and challenge water are shown to be representative) one sample before the splitter.	3 samples (start, middle, end)
Number of discharge samples	Zooplankton, live organ-	Minimum of 3 samples collected from the treat-	1 sample from the discharge of the control tank, and 1 sample	Dependent on Test Plan: IMO: 3 continuous time inte-

Parameter	Sub-category	IMO G8	ETV protocol	DHI
	isms ≥ 50 µm in size	ment track and 3 samples collected from the control track.	from the discharge (following any treatments) of the treated water.	grated samples (min 3 × 1 m^3) collected from the control and treatment lines upon discharge. Representative sub-samples analysed. USCG/ETV: 1 continuous time integrated sample (min 3 m^3) collected from the control and treatment lines upon discharge. The equivalent of an entire cubic meter of discharge water should be examined for the presence of live animals.
	Protists, live organisms ≥10-<50 µm in size	Minimum of 3 samples collected from the treatment track and 3 samples collected from the control track.	1 sample from the discharge of the control tank, and 1 sample from the discharge (following any treatments) of the treated water.	3 × 10 L per sample (start, middle, end). 100-300 mL sub-sample concentrated to 25 mL
	Bacteria	Minimum of 3 samples collected from the treatment track and 3 samples collected from the control track.	1 sample from the discharge of the control tank, and 1 sample from the discharge (following any treatments) of the treated water.	3 × 500 mL per sample (start, middle, end). Representative sub-samples analysed.
Analytic end-points: Discharge density	Zooplankton, live organisms ≥ 50 µm in size	Less than 10 viable organisms per m3 greater than or equal to 50 µm in minimum dimension for treated water; more than 100 viable organisms per m^3 greater than or equal to 50 µm in minimum dimension for control water.	Less than 10 viable organisms per m3 greater than or equal to 50 µm in minimum dimension for treated water; more than 100 viable organisms per m^3 greater than or equal to 50 µm in minimum dimension for control water.	Less than 10 viable organisms per m^3 greater than or equal to 50 µm in minimum dimension for treated water; more than 100 viable organisms per m^3 greater than or equal to 50 µm in minimum dimension for control water.
	Protists, live organisms ≥10-<50 µm in size	Less than 10 viable organisms per mL less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension for treated water; more than 100 viable organisms per mL less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension for control water.	Less than 10 viable organisms per mL less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension for treated water; more than 100 viable organisms per mL less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension for control water.	Less than 10 viable organisms per mL less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension for treated water; more than 100 viable organisms per mL less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension for control water.
	Bacteria	Less than 1 colony forming unit (CFU) per 100 mL or less than 1 CFU/1 g (wet weight) zooplankton of toxicogenic *Vibrio cholerae* (O1 and O139), less than 250 CFU/100 mL of *E. coli*, and less than 100 CFU/100 mL of intestinal enterococci for treated water	Less than 1 CFU per 100 mL or less than 1 CFU/1 g (wet weight) zooplankton of toxicogenic *Vibrio cholerae* (O1 and O139), less than 250 CFU/100 mL of *E. coli*, and less than 100 CFU/100 mL of intestinal enterococci for treated water; Minimum concentration in control tank discharge is 5 x 10^2/mL.	Less than 1 CFU per 100 mL of toxicogenic *Vibrio cholerae* (O1 and O139), less than 250 CFU/100 mL of *E. coli*, and less than 100 CFU/100 mL of intestinal enterococci for treated water; More than 5 × 10^2/mL of heterotrophic bacteria in control tank discharge.
Water quality measurements	N/A	pH, temperature, salinity, dissolved oxygen, TSS, DOC, POC and turbidity (NTU) should be measured at the same time that the samples are collected.	Temperature, salinity, TSS, POM, DOM, mineral matter, dissolved oxygen, pH, chlorophyll a.	pH, temperature, salinity, dissolved oxygen, and turbidity (NTU) is continually measured by on-line monitoring on intake and discharge. TSS, DOC, POC, mineral matter and primary production (indirect measure of chlorophyll a) are measured at the same time that the samples are collected

Parameter	Sub-category	IMO G8	ETV protocol	DHI
Toxicity	N/A	Separate samples should be collected for toxicity testing of treated water, from the discharge, for systems that make use of active substances and also for those, which could reasonably be expected to result in changes to the chemical composition of the treated water such that adverse impacts to receiving waters might occur upon discharge. Tests should conducted in accordance with Resolution MEPC.126(53)) paragraphs 5.2.3 to 5.2.7 as amended.	Toxicity tests will be conducted for treatments involving biocides. Tests will be selected from a short list of U.S. EPA standard tests.	Whole effluent toxicity (WET) tests and residual by-product chemical analyses of control and treated discharge water is performed for systems involving active substances. Tests will be selected from a short list of OECD Guideline standard tests.
Biological sample analysis	N/A	Samples should be analysed as soon as possible after sampling, and analysed live within 6 hour or treated in such a way as to ensure that proper analysis can be performed. Widely accepted standard methods for the collection, handling, storage, and analysis of samples should be used.	Zooplankton enumeration: Concentrate using 35 µm mesh plankton nets; no preservation; subsample into well plate (20 1mL wells observed); observe with dissecting microscope and probe organisms to determine live/dead status; fix with Lugol's for total counts. Phytoplankton enumeration: No preservation; stain with FDA and CMFDA; load into a Sedgewick Rafter Counting Chamber and examine under epifluorescence using a FITC narrow pass filter cube. Bacteria: Plate on appropriate media; use a DNA colony blot hybridisation for *V. cholerae.*	Zooplankton enumeration: Concentrate using 35 µm mesh plankton nets; no preservation; subsample into Borogov counting chamber, observe with dissecting microscope and probe organisms to determine live/dead status; fix with Lugol's for taxonomic evaluation. Phytoplankton enumeration: 1) No preservation; stain with FDA and CMFDA; load into a Sedgewick Rafter Counting Chamber and examine under epifluorescence; 2) Phytoplankton re-growth assay by use of most probable number (MPN) and 3) Measurements of phytoplankton primary production. Bacteria: Enumeration of total viable heterotrophic bacteria, *E. coli*, and enterococci and preparation of colony blots for the detection of toxicogenic *V. cholerae.*
Flow rate	N/A	At least 200 m^3/hr.	At least 200 m^3/hr.	Up to 500 m^3/hr. and not lower than 100 m^3/hr.
Number and capacity of retention tanks	N/A	At least 1 control and 1 treatment tank with a minimum capacity of 200 m^3 each.	At least 1 control and 1 treatment tank with a minimum capacity of 200 m^3 each.	2 control and 4 treatment tanks each with a capacity of 250 m^3.
Control/ treatment cycle sequence	N/A	Control and treatment cycles may be run simultaneously or sequentially.	Control and treatment cycles may be run simultaneously or sequentially.	Control and treatment cycles are typically run sequentially on uptake and on discharge
Retention time	N/A	At least 5 days.	Minimum of one day.	1 to 5 days, dependent on Test Plan.
Number of trials	N/A	At least 5 successes.	Minimum of five consecutive valid per salinity regime.	Minimum of 5 successful test cycles per salinity regime.
QA/QC	N/A	Quality Management Plan (QMP) addressing the quality control management structure and policies of the testing body, including subcontractors and outside laboratories; Quality Assurance Project Plan (QAPP) addressing the	A Test Plan with detailed test objectives, specific test procedures and quality control and assurance requirement shall be developed. A QAPP (annexed to the Test Plan), is to be compiled by the Testing Organisation, with input from the vendor. The QAPP will describe the proce-	Quality Management Plan (QMP) addressing the quality control management structure and policies of DHI; Quality Assurance Project Plan (QAPP) addressing the specifics of the DHI's biological efficacy performance evaluation of BWMS, its facilities, and other conditions affecting the

Parameter	Sub-category	IMO G8	ETV protocol	DHI
		specifics of the ballast treatment technology to be tested, the test facility, and other conditions affecting the actual design and implementation of the required experiments.	dures for conducting a test or study according to the verification protocol requirements for the application of a ballast water treatment system at a particular site. At a minimum, the QAPP shall detail test objectives, specific test procedures (including sample and data collection, sample handling, analysis and preservation), and quality control and assurance requirements (including measures of precision, accuracy, comparability, and representativeness).	actual design and implementation of the required experiments. A Test Plan describing the project specific details reflecting the Contract between the manufacturer and DHI.

5.1.2 Source water

Source water means the body of water, from which water is drawn for the land-based test. The IMO G8 guidelines /2/ and the ETV protocol /5/ describe three distinct water types that may be applied in the land-based test:

Fresh water (salinity <1 PSU)
Brackish water (salinity 10-20 PSU)
Marine water (salinity >32-36 PSU)

When fresh water is used, the source water will be collected in the Arresø Canal according to DHI SOP 30/1736 on collection of fresh water. Organism densities in the collected fresh water often exceed the minimum criteria for live organisms in test water with an order of magnitude allowing for dilution of the natural fresh water with potable water.

When brackish water is used, the source water will be collected immediately south of the pier adjacent to the test facility according to DHI SOP 30/1735; under normal conditions, the natural salinity of the source water will be 15-20 PSU.

When marine water is used, the source water will be collected immediately south of the pier adjacent to the test facility according to DHI SOP 30/1735, and brine will be added to achieve the required salinity.

5.1.3 Biological efficacy test cycles

5.1.3.1 BWMS treatment process

The biological efficacy (BE) test cycles will be conducted by use of the source tank (Tank D), control tank (Tank A1 or A2) and one retention tank per test cycle (Tank B1, B2, C1 or C2) (Figure 3.1).

The following steps are involved in the treatment of the test water in the BWMS (for definition and characterisation of test water, see Section 5.2):

1. A fraction of the test water (minimum 200 m^3 and maximum 250 m^3) contained in the source tank is transferred to the BWMS by pumping and treated here, after which it is transferred to one of the retention tanks (treated water).

2. Another fraction of the same test water (minimum 200 m^3 and maximum 250 m^3) is pumped directly into the control tank without passing the BWMS (control water). The control water serves as a control of BWMS performance.

3. Piping system and sample ports are cleaned (DHI SOP 30/1763).

For each BE test cycle, a minimum operational period of one (1) hour is required although this may be extended if the flow rate are lower than 200 m^3 per hour (as described in Section 5.4.5 in the ETV protocol /5/). The minimum operational period may decrease if the flow rate of the BWMS is higher than 200 m^3 per hour.

During ballasting, the flow, pressure, temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks are recorded automatically (DHI SOP 30/1764).

Samples are collected before and after first treatment by use of the relevant sample ports. Sampling is initiated when the flow rate has reached steady-state conditions, i.e. up to 5 minutes from start of operation (DHI SOPs 30/1738 and 30/1762). The samples are labelled according to procedures described in DHI SOP 30/1750.

5.1.3.2 Storage of treated and untreated test water

Following the treatment of the test water in the BWMS, the treated water is stored in the retention tank for at least five days ± 4 hours. The same storage time is applied for the control water.

5.1.3.3 Second treatment and discharge of test water

1. Treated water contained in the retention tank is pumped through the BWMS for second treatment, after which it is discharged into the harbour (treated discharge water)

2. Control water contained in the control tank is discharged into the harbour (control discharge water)

3. The retention tanks, piping system and sample ports are cleaned (DHI SOP 30/1763)

During de-ballasting, the flow, pressure, water temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks are recorded automatically (DHI SOP 30/1764).

Samples of the treated discharge water are collected by use of the sampling ports on the BWMS discharge line whereas samples of the control discharge water are collected by use of sampling ports on the test facility discharge line. Isokinetic sampling methodology with fixed sample volumes is applied according to principles described in MEPC.173(58) (G2) /9/.

5.1.4 Whole effluent toxicity testing

Whole effluent toxicity (WET) tests are conducted with treated discharge water and control discharge water in connection to BE test cycles. The WET testing includes chronic ecotoxicity tests covering three trophic levels (algae, crustaceans, fish). The WET tests are conducted in accordance with OECD Test Guidelines or ISO standards:

- Algae: OECD TG No. 201. Algal growth inhibition test (72 hours)
- Crustaceans: ISO/TC 147/SC5 ISO/CD 16778 (Draft 2012) ”Water quality - Calanoid copepod early-life stage test with *Acartia tonsa* (5 days)
- Crustaceans: OECD TG No. 211. Daphnia magna reproduction test (21 days)
- Fish: OECD TG No. 212. Fish, embryo sac fry test (10 days)

WET tests are included as part of the performance evaluation of BWMS in accordance with the requirements in Resolution MEPC.174(58) (IMO G8 guidelines) /2/ and Resolution MEPC.169(57) (IMO G9 guidelines) /3/. The WET tests are supplemented with chemical analyses of disinfection by-products in the case that the IMO G9 guidelines are applied.

5.1.5 Operation and maintenance testing

The operation and maintenance (O&M) testing of the BWMS shall distribute testing of a minimum treated volume of 10,000 m^3 amongst the BE test cycles. The minimum total volume for the O&M test cycles is achieved by conducting five O&M test cycles, each with a minimum treated volume of 2,000 m^3.

5.2 Challenge conditions in BE verification testing

5.2.1 Test water – water quality characteristics

Test water (equivalent to the term challenge water /4; 5/) means the inlet water as contained in the source tank just prior to treatment. In land-based tests, source water may be adjusted to achieve the required challenge conditions.

The natural concentrations of dissolved organic carbon (DOC), particulate organic carbon (POC) and total suspended solids (TSS) in the source water are analysed, after which the test water will be prepared to meet the water quality parameters in Table 5.2.

Table 5.2 Minimum water quality characteristics according to the IMO G8 guidelines /2/ and the ETV protocol /5/ in parentheses

Parameter	Source water		
	Fresh (<1 PSU)	Brackish (10-20 PSU)	Marine (>32-36 PSU)
Dissolved organic carbon (DOC)	≥ 5 (6) mg/L	≥ 5 (6) mg/L	≥ 1 (6) mg/L
Particulate organic carbon (POC)	>5 mg/L	≥ 5 mg/L	≥ 1 (4) mg/L
Total suspended solid (TSS) Mineral materials (MM) ≥ 20 mg/L	>50 mg/L	≥ 50 mg/L	≥ 1 (24) mg/L

If necessary to obtain the stated water quality parameters, the concentrations of DOC, POC and mineral materials (MM) are increased by additions of lignin sulphonate (DOC), starch (POC) and kaolin clay (MM) as described in DHI SOP 30/1737.

5.2.2 Test water – biological organism conditions

The natural densities of live organisms in the source water are analysed with reference to size classes, after which the test water is prepared to meet the biological parameters in Table 5.3.

Table 5.3 Minimum densities of live organisms in the test water according to the IMO G8 guidelines /2/ and the ETV protocol /5/

Organism size class	Total concentration	Diversity
≥50 µm	10^5 organisms/m^3	5 species across 3 phyla
≥10 µm and <50 µm	10^3 organisms/mL	5 species across 3 phyla
<10 µm (only ETV protocol)	10^3/mL as culturable aerobic heterotrophic bacteria	Not applicable

If necessary in order to obtain the stated minimum criteria, the densities of live organisms are increased by addition of harvested indigenous organisms and/or cultured species as described in DHI SOP 30/1734. Addition of harvested and/or cultured species is recorded in the data logging. Heterotrophic bacteria are typically present in the source water in densities exceeding the minimum criteria described in Table 5.3.

The minimum densities of live organisms in the control discharge water are presented in Table 5.4.

Table 5.4 Minimum densities of live organisms in the control discharge water according to the IMO G8 guidelines /2/ and the ETV protocol /5/

Organism size class	Total concentration
≥ 50 µm	100 organisms/m^3
≥10 µm and < 50 µm	100 organisms/mL
<10 µm (only ETV protocol)	5×10^2/mL as culturable aerobic heterotrophic bacteria

5.3 Sampling and analysis plan

A complete description of the sampling and analyses is provided in the Test Plan.

5.4 Analytical procedures

The specific analyses applied in the land-based test and the associated DHI SOPs are described in Chapter 7.

6 Performance evaluation in shipboard test

6.1 Experimental design

6.1.1 Source water

The source water used for the testing shall be representative of harbour or coastal waters. The natural densities of live organisms in the source water are analysed with reference to size classes. The densities of live organisms in the size classes ≥50 µm and ≥10 µm to <50 µm (Table 6.1) must exceed 10 times the maximum permitted values in the IMO D-2 standard /1/, which is similar to the ballast water discharge standard /4/.

Table 6.1 Minimum densities of live organisms in the source water in shipboard test according to the IMO G8 guidelines /2/ and the U.S. Coast Guard Standards /4/

Organism size class	Total concentration	Diversity
≥50 µm	100 organisms/m^3	No requirement
≥10 µm and <50 µm	100 organisms/mL	No requirement

6.1.2 Biological efficacy test cycles

The organisation of the BE test cycles and the associated trial periods and locations are described in the Test Plan.

6.2 Sampling and analysis plan

A complete description of the sampling and analyses is provided in the Test Plan.

6.3 Analytical procedures

The specific analyses applied in the shipboard test and the associated DHI SOPs are described in Chapter 7.

7 Data management, analyses and reporting

7.1 Data management

During the land-based or shipboard test information is recorded in relation to

- Personnel participating in cleaning and maintenance at the test facility and collection of samples

- Operational procedures and monitoring
- Sampling and analysis

The data are recorded in accordance with the data-logging procedures described in the respective SOPs. A complete overview of the DHI SOPs used for BWMS performance evaluation in land-based or shipboard tests is presented in Appendix B.

An Access-based database and the procedures described in DHI SOP 30/1750 are used for storage of data generated from the BE test cycles and for marking completed QC of individual data. This data-level QC is made with reference to data quality indicators (DQI) described in the SOPs.

All generated data and all other records and information relevant to the quality and integrity of the performance evaluation, including a copy of the database file(s) and original raw data, is retained in the archives of DHI for a period of five years after issue of the final report.

7.2 Analyses

7.2.1 Organism size class ≥50 μm

Compliance with the pass criterion in Chapter 9 will be verified by use of the direct count of organisms ≥50 μm in minimum dimension.

The concentrations of live organisms ≥50 μm in minimum dimension are determined by use of a stereo microscope and a counting chamber according to DHI SOP 30/1700. Viable organisms are enumerated by use of standard movement and response stimuli technique. The viable organisms are characterized according to broad taxonomic groups such as crustaceans (e.g. copepods), molluscs, rotifers, worms, etc.

7.2.2 Organism size class ≥10 μm and <50 μm

Compliance with the pass criterion in Chapter 9 will be verified by use of a combination of methods which shall be stated in the Test Plan.

Verification of compliance with the pass criterion for the size class ≥10 and <50 μm in minimum dimension is not straight-forward, because conventional vital staining is not directly applicable for determination of live organisms of all ballast water management technologies. E.g., ultra violet (UV) radiation may kill the organisms, but the esterase activity causing the response of the vital stains chloromethylfluorescein diacetate (CMFDA) and fluorescein diacetate (FDA) is not immediately inactivated, and this will result in "false positive" counts. Therefore, a combination of methods is used to determine the concentrations of live organisms in the size class ≥10 and <50 μm.

Examples:

For BWMS using e.g. active substance(s), compliance with the pass criterion in Chapter 9 may be verified by use of the direct count of CMFDA/FDA labelled organisms ≥10 and <50 μm in minimum dimension by use of an epifluorescence microscope.

For BWMS using filtration and UV radiation, compliance with the pass criterion in Chapter 9 may be verified by use of the total of viable organisms determined by measuring algal re-growth using a most probable number (MPN) assay and enumeration of viable moving organisms ≥10 and <50 μm in minimum dimension that are not encompassed by the algal re-growth assay (i.e. CMFDA/FDA labelled organisms without chlorophyll).

To support the determination of concentrations of organisms in the ≥10 μm and <50 μm size class, a combination of the following analytical methods may be applied. The selection of methods shall be stated in the Test Plan:

Inverted microscopy (DHI SOP 30/1701). The concentrations of organisms and the presence of taxonomic groups in the inlet water are determined by inverted microscopy. Inverted microscopy is also be used to determine the taxonomic groups of algae that are able to grow under the conditions applied in the algal re-growth assay.

Vital staining with CMFDA and FDA (DHI SOP 30/1701). CMFDA and FDA are added to a subsample and, after incubation, the subsample is examined by use of a microscope under epifluorescence. Organisms labelled by either CMFDA or FDA are considered viable as described in DHI SOP 30/1701.

Algal re-growth assay (DHI SOP 30/1704). Viable algae are quantified by measuring re-growth in a most probable number (MPN) assay. A dilution series is prepared by adding aliquots of subsample to test tubes with liquid medium. The test tubes are incubated for 14 days at ambient temperature. The concentrations of viable algae in the inlet water, control discharge water and treated discharge water are determined by measuring of the fluorescence in the test tubes before and after incubation according to DHI SOP 30/1704. The algal re-growth assay is considered to provide the most reliable results to be used for a performance evaluation of BWMS applying UV treatment as the method is directly linked to algal growth and, thus, indicative of the ability of the organisms to establish and reproduce in the environment. The algal re-growth assay includes planktonic algae without reference to size, and, thus, it is not limited to the ≥10 µm and <50 µm size class.

Algal primary production (DHI SOP 30/1702). The algal primary production is determined by measuring the ^{14}C fixed by photosynthesis. For each field replicate, $NaH^{14}CO_3$ (2 µCi) is added to two subsamples. These subsamples are incubated for approx. 75 min under light from a light panel at ambient temperature. After incubation, the samples are filtered onto Whatman GF/D filters. The filters are transferred to glass vials, and acid is added directly to the filters to release $^{14}CO_2$. The ^{14}C activity remaining in the algae on the filters after acidification is quantified by liquid scintillation counting according to DHI SOP 30/1702. The algal primary production assay includes planktonic algae without reference to size, and, thus, it is not limited to the ≥10 µm and <50 µm size class.

7.2.3 Organism size class <10 µm (bacteria)

The concentrations of heterotrophic aerobic bacteria are determined according to DHI SOP 30/1706 (ISO 6222). *E. coli* and enterococci are analysed according to DHI SOP 30/1708. *Vibrio cholerae* is analysed according to the method described in DHI SOP 30/1707 (ISO 21872).

7.2.4 Physical/chemical analyses

The physical/chemical analyses conducted according to DHI SOPs 30/1764 and 30/1766 include:

Land-based test:

- pH
- Turbidity
- Dissolved oxygen
- Ballast system pressure
- Ballast system flow rates
- UV-transmittance at 254 nm, 1 cm
- Water volume in retention tanks

Land-based and shipboard test:

- Temperature
- Salinity
- Dissolved organic carbon (DOC)
- Particulate organic carbon (POC)
- Total suspended solids (TSS)

8 Validity criteria

8.1 Land-based test validity criteria

A valid BE test cycle implies that the average concentrations of viable organisms in the control discharge water exceed the minimum densities in Table 5.4:

- 100 organisms per m^3 for the size class ≥50 µm (IMO G8 guidelines, Annex, Part 2, Section 2.3.36 /2/; ETV protocol, Section 5.4.7.3 /5/)
- 100 organisms per mL for the size class ≥10 µm and <50 µm (IMO G8 guidelines, Annex, Part 2, Section 2.3.36 /2/; ETV protocol, Section 5.4.7.3 /5/)
- 500 per mL for the size class <10 µm (ETV protocol, Section 5.4.7.3 /5/)

The test report shall verify that the criteria for a valid BE test were met, or deviation from the criteria shall be scientifically justified (e.g., grazing by high numbers of zooplankton may imply that the required density for the size class ≥10 µm and <50 µm cannot be accomplished in the control water at discharge).

Although the water quality and the biological challenge conditions are not defined as validity criteria in the IMO G8 guidelines /2/ and the ETV protocol /5/, the test water should meet the minimum water quality characteristics in Table 5.2 and the minimum densities of live organisms and diversity ranges in Table 5.3.

The minimum water quality characteristics and the minimum densities of live organisms in the test water shall ensure that relevant challenge conditions are obtained in the BE test. The challenge conditions in Tables 5.2 and 5.3 can normally be met by the preparation of the test water, but natural variation in the composition of the source water may occasionally result in concentrations of DOC, POC and TSS or densities of live organisms that are slightly lower than the minimum values. A deviation of less that 10% below the minimum values in Tables 5.2 and 5.3 is considered relevant challenge conditions that do not impair the validity of the BE test. Any deviation in the average concentrations below 90% of the minimum values shall be clearly described and discussed in test report.

8.2 Shipboard test validity criteria

A valid BE test cycle implies that:

- The average concentrations of viable organisms in the source water are at least 10 times higher than the maximum permitted values in the IMO D-2 standard (IMO G8 guidelines, Annex, Part 2, Section 2.2.2.5 /2/), excepted from the requirements to bacteria, which is similar to the ballast water discharge standard (U.S. Coast Guard standards, §162.060-28 /4/). Minimum densities of live organisms are provided in Table 6.1
- The average concentrations of viable organisms in the control discharge water exceed the maximum permitted values in the IMO D-2 standard (IMO G8 guidelines, Annex, Part 2, Section 2.2.2.5 /2/) except for the requirements to bacteria, which is similar to the ballast water discharge standard (U.S. Coast Guard standards, §162.060-28 /4/).

9 Pass criteria

A valid BE test cycle, as part of either a land-based or a shipboard test, is regarded successful if it meets the performance standard for treated ballast water at discharge (IMO Regulation D-2 /1/ and United States Coast Guard /4/ (§151.2030)):

1. The average density of organisms larger than or equal to 50 µm in minimum diameter in the replicate samples shall be less than 10 viable organisms per m^3 at discharge

2. The average density of organisms smaller than 50 µm and larger than or equal to 10 µm in minimum diameter in the replicate samples shall be less than 10 viable organisms per mL at discharge

3. The average density of *Vibrio cholerae* (serotypes O1 and O139) shall be less than 1 colony forming unit (CFU) per 100 mL at discharge

4. The average density of *E. coli* in the replicate samples shall be less than 250 CFU per 100 mL at discharge

5. The average density of intestinal enterococci in the replicate samples shall be less than 100 CFU per 100 mL at discharge

10 Quality assurance and control

10.1 Quality assurance

The project is conducted in accordance with the principles of ISO 9001 by using the DHI Business Management System and the procedures in the QMP /6/.

The DHI quality manager is responsible for assigning a trained internal auditor from DHI's Quality Assurance Unit to each project in accordance with the procedures for internal audit in the DHI Business Management System (Section on Quality). The internal auditor shall not be involved in solving the specific project or in any project deliverables.

The DHI Business Management System (Section on Quality; Internal Audit) describes procedures for audit and evaluation and the process of periodic internal auditing of projects and activities including audit responsibilities and planning, auditor training and competences and audit reporting.

The DHI Business Management System (Section on Quality; Correction and Prevention) describes procedures for corrective actions, i.e. how deviations identified during operation and auditing are corrected and how future occurrence of the same deviations is prevented (preventive actions).

10.2 Quality control

Quality control of individual data, or data-level QC, of BWMS operational conditions, sampling and analyses is conducted with reference to data quality indicators (DQI) in the DHI SOPs by staff appointed for this task (see Section 2.2). The DQI include accuracy, precision, bias, representativeness, completeness, comparability, and sensitivity. The DQI and how they are monitored and evaluated are described in the relevant DHI SOPs.

Records of completed data-level QC are stored in an Access-based database (DHI SOP 30/1750), and a copy of the relevant database file(s) will be retained in the DHI archives for a period of five years after issue of the final report.

Quality control of the QAPP, DHI SOPs and all project proposals, deliverables and reports is conducted by management (see Section 2.2).

11 References

/1/ IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments. London. International Maritime Organization, 2004.

/2/ MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10th October 2008.

/3/ MEPC. Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9). Resolution MEPC.169(57) Adopted 4th April 2008.

/4/ U.S. Coast Guard. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters. Federal Register, Vol. 77, No. 57, March 23, 2012.

/5/ U.S. Environmental Protection Agency, Environmental Technology Verification Program. Generic Protocol for the Verification of Ballast Water Treatment Technology. EPA/600/R-10/146, September 2010.

/6/ Quality management plan. Performance Evaluation of Ballast Water Management Systems. DHI Denmark. Version 3.1. May 2012.

/7/ EN ISO/IEC 17025. General requirements for the competence of testing and calibration laboratories /ISO/IEC 17025, 2005.

/8/ OECD Principles of Good Laboratory Practice (as revised in 1997). Organisation for Economic Co-operation and Development (OECD), Paris. ENV/MC/CHEM (98)17.

/9/ Resolution MEPC.173(58). Adopted on 10 October 2008. Guidelines for approval of ballast water sampling (G2).

APPENDIX A

Certificate of compliance, ISO 9001 certificate,
accreditation and GLP authorisation

COPY

Certificate no: **DS/I093222-A**
Page 1 of 1

Lloyd's Register

Certificate of Compliance

Office: **Lloyd's Register EMEA**
Copenhagen Design Support Centre, Statutory Section
Strandvejen 104A, 2nd floor
DK-2900 Hellerup
Denmark

Date: **09 May 2012**

This certificate is issued to **DHI Ballast Water Centre, Denmark**

DHI Ballast Water Centre, Denmark

The Document(s) listed in paragraph 1 of the appendix have been examined for compliance with:

- Resolution MEPC.174(58), Annex part 2

and are found to comply from quality assurance and quality control aspects subject to the following:

1.1. It is required to maintain full and accurate log files in order to demonstrate correct quality measures

1.2. The Quality Assurance Project Plan is a project specific document and should as such be subject to review and commenting prior to each project start-up.

1.3. This design appraisal document is to be kept together with quality management plan.

1.4. Subject certificate is valid until 15 June 2015.

1. The documents listed below have been examined

Drawing No.	Rev.	Title	Status	Date
Date: 07 Sep 2011	**2.3**	**Quality Management Plan**	**B**	**09 May 2012**

2. The documents listed below have been considered together with the submitted documents in the appraisal

Drawing No.	Rev.	Title
11810704	**02**	**Quality Assurance Project Plan**

Appraisal Status Key

B Examined and found to comply with §2.2, Part 2 of the annex of IMO Resolution MEPC 174 (58)

Martin Schabert
Statutory Department
Copenhagen Design Support Centre
Surveyor to Lloyd's Register EMEA

LLOYD'S REGISTER EMEA
Lloyd's Register
M. Schabert
COPENHAGEN DESIGN SUPPORT CENTRE

A member of the Lloyd's Register Group

Form 1124 (2005.02)

DNV BUSINESS ASSURANCE

MANAGEMENT SYSTEM CERTIFICATE

Certificate No. 109333-2012-AQ-DEN-DANAK

This is to certify that

DHI Group

has been found to conform to the management system standard:

DS/EN ISO 9001:2008

This certificate is valid for the following product or service ranges:

Consulting, software, research & development and laboratory testing, analysis & products within the area of water, environment & health

Locations included in the certification will appear in the appendix.

Place and date:
Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

This certificate is valid until:
2015-01-10

DANAK
SYSTEM Reg.nr. 5001

The audit has been performed under the supervision of:

Jan Carsten Schmidt
Lead Auditor

Jens Peter Høiseth
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

ACCREDITED UNIT: DET NORSKE VERITAS, BUSINESS ASSURANCE, DANMARK A/S, TUBORG PARKVEJ 8, 2., DK-2900, HELLERUP, DANMARK, TEL:+45 39 45 48 00, WWW.DNVBA.COM

DNV BUSINESS ASSURANCE

APPENDIX TO CERTIFICATE

This appendix refers to certificate no. 109333-2012-AQ-DEN-DANAK

DHI Group

Locations included in the certification are as follows:

Site Address	Scope:
Agern Allé 5 2970 Hørsholm, Denmark	Consulting, MIKE© by DHI Software Development, Sales & Support, Solutions Software Development, Research, Development & Innovation and Laboratory Analysis, Testing & Products
INCUBA Science Park, Gustav Wieds Vej 10 8000 Århus, Denmark	Consulting, Solutions Software Development and Research, Development & Innovation
Drakegatan 6, 412 50 Göteborg, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Kyrkogatan 3, 222 22 Lund, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Svartmangatan 18, 111 29 Stockholm, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Honnörsgatan 16, Box 3287, 350 53 Växjö, Sweden	Consulting, MIKE© by DHI Software Sales & Support

Place and date:

Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

This certificate is valid until:

2015-01-10

The audit has been performed under the supervision of:

DANAK
SYSTEM Reg.nr. 5001

Jan Carsten Schmidt
Lead Auditor

Jens Peter Høiseth
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

ACCREDITED UNIT: DET NORSKE VERITAS, BUSINESS ASSURANCE, DANMARK A/S, TUBORG PARKVEJ 8, 2., DK-2900, HELLERUP, DANMARK, TEL:+45 39 45 48 00, WWW.DNVBA.COM

Accreditation to testing

COPY DANAK

Company: **DHI**

Agern Allé 5
DK-2970 Hørsholm

Registration number: **26**

Valid: **24-10-2012 to 31-07-2015**

Scope:

Testing

Product
- **Biological items**
- **Chemicals and chemical products**
- **Construction products**
- **Environmental samples**

Test Type
- **Biological and biochemical testing**
- **Chemical testing**
- **Microbiological testing**
- **Ionising radiation and radiochemistry**
- **Sampling**

Testing is performed according to the current list of test methods approved by DANAK.

The company complies with the criteria in EN ISO/IEC 17025:2005 – General requirements for the competence of testing and calibration laboratories and demonstrates technical competence for the defined scope and the operation of a quality management system (refer joint ISO-ILAC-IAF Communiqué dated January 2009, www.danak.dk).

Issued the 24 October 2012

f. Jesper Høy / **Kirsten Jebjerg Andersen**

In case of any disputes, the Document in Danish language shall have priority.

Den Danske Akkrediterings- og Metrologifond

COPY

DANAK

GOOD LABORATORY PRACTICE

STATEMENT OF COMPLIANCE

Laboratory inspection and study audits for compliance with the OECD Principles for Good Laboratory Practice were carried out at

Laboratory: DHI

on

Dates: 21st and 22nd October 2011

The laboratory inspection and study audits have been carried out in accordance with the regulation settled in Order No. 906 of 14th September 2009 from the Danish Ministry of Environment. The laboratory has been monitored for GLP Compliance within the following scope:

Type of products:

- *Industrial chemicals*
- *Pesticides*
- *Biocides*

Type of tests:

- *Environmental toxicity studies on aquatic and terrestrial organisms.*
- *Studies of behaviour in water, soil and air, bioaccumulation*

The laboratory was found to be operating in compliance with the OECD Principles of Good Laboratory Practice.

Date: 08 August 2012

Jesper Høy
Managing director, DANAK

Kirsten Jebjerg Andersen
GLP inspector, DANAK

Den Danske Akkrediterings-
og Metrologifond

APPENDIX B

Overview of DHI SOPs

SUBJECT/SUBSUBJECT	DHI SOP NO.
ANALYTICAL METHOD DETERMINATION OF VIABLE ORGANISMS ≥50 μm	30/1700
ANALYTICAL METHOD DETERMINATION OF VIABLE ORGANISMS ≥10 μm AND < 50 μm	30/1701
ANALYTICAL METHOD DETERMINATION OF PRIMARY PRODUCTION OF MICROALGAE	30/1702
ANALYTICAL METHOD DETERMINATION OF VIABLE ALGAE BY RE-GROWTH ASSAY	30/1704
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL NUMBER OF BACTERIA BY EPIFLUORESCENCE MICROSCOPY	30/1705
MICROBIOLOGICAL TESTS DETERMINATION OF HETEROTROPHIC PLATE COUNT	30/1706
MICROBIOLOGICAL TESTS DETERMINATION OF *VIBRIO CHOLERAE* IN WATER	30/1707
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL COLIFORM, E.COLI AND ENTEROCOCCI	30/1708
MEASUREMENT METHOD TRO MEASUREMENT IN WATER	30/1732
HARVESTING, CULTURING AND ADDITION OF ORGANISMS	30/1734
COLLECTION OF SEAWATER	30/1735
COLLECTION OF FRESH WATER	30/1736
CRITERIA FOR TEST WATER ADDITION OF DOC, POC, MM AND BRINE	30/1737
SAMPLING PREPARATION, SUBSAMPLING AND TRANSPORTATION OF SAMPLES	30/1738
DATABASE SAMPLES, LABELS AND DATA SHEETS	30/1750
OPERATION OF THE DHI MTEF	30/1762
CLEANING RETENTION TANKS; PIPINGS AND OTHER EQUIPMENT AT TEST SITE	30/1763
MEASUREMENT METHOD ON-LINE MONITORING OF PRESSURE, TEMPERATURE, FLOW RATES AND QUALITY PARAMETERS AT TEST SITE	30/1764
MEASUREMENT METHOD FLUORESCENCE	30/1765
MEASUREMENT METHOD TURBIDITY	30/1766
DHI MTEF HEALTH AND SAFETY	30/1767
MEASUREMENT METHOD DETERMINATION OF TSS	30/1768
MEASUREMENT METHOD DETERMINATION OF DOC AND POC	30/1769
MEASUREMENT METHOD DETERMINATION OF TRANSMITTANCE	30/1770

APPENDIX B

Description of the ballast water management system as provided by the manufacturer

SYSTEM
DESCRIPTION

Trojan Marinex^{TM} BWT 500

Contents:

1. Process and equipment design

General description

Trojan Marinex^{TM} BWT 500 is a fully integrated Ballast Water Treatment System (BWTS) specifically designed for marine environments at a treated rated capacity 500 meters cube per hour. The system is unique in that it combines two purely physical treatment processes, both filtration, and UV disinfection in one single unit. Combining the treatment processes preserves a small footprint and increases the ability to locate the system within the vessel. Having combined the treatment processes in one single unit reduces the complex interconnecting piping and the associated pressure loss.

The system operation can be fully automated and integrated into a vessels ballasting system or can be managed separately through the controls of the ballast water treatment equipment.

The starting sequence of treatment occurs when the inlet valve is opened, allowing ballast water to enter. While the system starts filling the lamp initiation sequence is activated. Additionally, at the end of the filling cycle when the system is full the lamp wiper starts a cleaning cycle. Once the system is completely full the outlet valve is opened and the treatment process begins. The system control works together with a flow transmitter and the pump of the vessel.

Filtration is the first stage in the treatment process. Filtration removes particles and larger organisms, while evenly distributing the flow of the ballast water into the UV section of the treatment unit. Filtered water flows through the UV section of the treatment unit targeting all organisms not removed in the filtration process.

The final stage of the treatment process occurs during de-ballast. Previously treated water (filtered + UV) is moved from the ballast tank to the de-ballast inlet of the treatment unit. During this final stage the water only moves through the UV portion of the treatment unit and then discharged to sea.

The Trojan Marinex^{TM} BWT 500 consists of the following principal components;

<u>Treatment Unit</u>

- 316L stainless steel construction containing;
    - Twenty-four (24) super duplex custom designed filter elements for marine use.
    - Forty-eight (48) Low pressure high efficiency UV lamps (500 Watts each):
        - Using the TrojanUV Solo Lamp^{TM} Technology

- Automatic filter cleaning
- Automatic lamp cleaning
- One (1) UVI sensor
- One (1) Temperature sensor
- One (1) Level sensor
- Two (2) Pressure sensors (inlet & outlet)
- De-Aerators
- Drain assembly

Treatment Unit Cabinets

Power Distribution Cabinet
- Houses the main system power, and breakers.
- Distributes power to all components of the treatment system.

Control Cabinet
- Houses the PLC and other system control function components. The control switches and HMI are mounted on the door of the cabinet.

Lamp Driver Cabinet(s)
- Provides a clean environment for the lamp drivers and connection for all lamp cables.

Pneumatic Cabinet
- Contains all solenoid valves, and pneumatic controls for valves.

Hydraulic Cabinet
- Provides all required hydraulic components for the lamp cleaning system.

Note: All cabinets are wall mounted

Detailed Process Description

Filling

Depending on the mode of operation (ballast or deballast) the inlet or de-ballast inlet are opened to allow water to be moved into the treatment unit. Water can enter the system by gravity, with the ballast pump, and or an alternative filling pump. All other valves remain closed until the treatment unit is full, triggered by the level switch. While the treatment unit is full the lamp cleaning sequence is initiated. The duration of the filling sequence varies for each installation type and associated piping. When the system is full the outlet valve is opened and ballast water can begin to flow.

Automatic Lamp Cleaning System

Lamp cleaning initiates automatically. Typically cleaning sequence is initiated at the start of a filling sequence and at the end of a cycle. Ultraviolet lamps incorporated in all ballast water treatment systems are housed in quartz sleeves. These quartz sleeves can become fouled with debris on the sleeve surface reducing the amount of ultraviolet light available for treatment. The lamp cleaning system removes any fouling that could build up on the lamp sleeves. The lamp cleaning sequence is initiated automatically at the start and end of ballast or a de-ballast cycle and based on the time of operation. The system does not need to be stopped during a cleaning cycle.

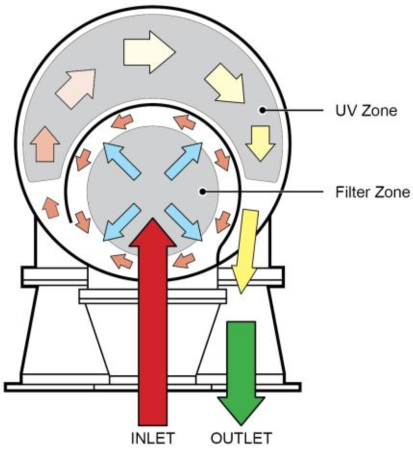
The automatic lamp cleaning system is sequentially driven. Each lamp wiping mechanism consists of a wiper plate, wiping seals and a drive cylinder. The drive cylinder moves the wiper plate with wiping seals from one end of the lamp sleeve to the other. A cleaning sequence consists of actuating the lamp cleaning system from its home position to the end of the lamp sleeves and back to the home position. The cleaning cycle is finished when the last lamp wiping mechanism reaches its home position. The benefit of having the cleaning process sequentially driven reduces disruption to flow and allows the ballasting or deballasting process to continue.

Each drive mechanism is magnetically coupled to a hydraulic drive cylinder. The drive cylinder is hermetically sealed to prevent the possibility of fluid loss. The carriage of the drive cylinder is home to the wiper plate and is magnetically coupled to the cylinder. All hydraulic connections are located on the outside of the treatment unit (non wetted area). Hydraulic fluid used to drive the cylinder ensures a smooth cleaning cycle.

Extensive development has gone into the design of the sleeve to support the lamp technology. Quartz is used as the sleeve material. Quartz is used in this application because it has a low thermal expansion, high thermal shock resistance, good dielectric properties, chemical inertness and good high temperature properties. Most importantly, it has a very high transmission of UV light.

Ballasting

The ballast sequence of treatment process occurs when the inlet valve is opened, allowing ballast water to enter the treatment unit. Filtration is the first stage in the treatment process. Filtration removes particles and targets larger organisms, while providing an evenly distributed flow of the ballast water into the UV section of the treatment unit. Filtered water flows through the UV section of the treatment unit targeting all organisms not removed in the filtration process. The treated water is directed to the ballast water tank through the ballast water outlet.



BALLASTING

Automatic Filter Cleaning System

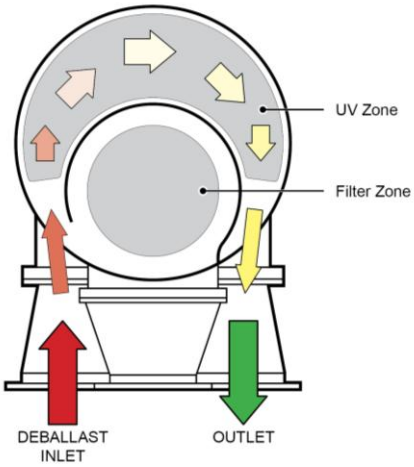
Each treatment unit is equipped with an automatic filter cleaning system. The cleaning system initiates when differential pressure is measured across the inlet and outlet of the ballast water treatment system. Each treatment unit has two pressure sensors, one located on the ballast water inlet and the other on the ballast water outlet. These pressure sensors provide a signal to the control panel to initiate a cleaning sequence. The cleaning sequence consists of opening an actuated backwash valve and signaling the filter drive motor to make one revolution. Each revolution of the drive motor allows each filter element to reverse its flow allowing accumulated debris trapped by the filter to be carried out to drain.

During the cleaning cycle, a flow meter is used in conjunction with a regulating valve to maintain consistent flow rate through the treatment unit. The treated rated capacity can be maintained while the system is in a filter cleaning cycle.

The cleaning system removes a filter from the process and allows filtered water to be diverted back across the filter removing trapped debris. The debris that is dislodged is then diverted back to its original source water. As each individual filter element is cleaned, the remaining filter elements continue to process water. Once the filter drive motor has completed its cycle, the backwash valve closes completing the cleaning sequence.

De-ballasting

The final stage of the treatment process occurs during de-ballast. Previously treated water (filtered + UV) is moved from the ballast tank to the de-ballast inlet of the treatment unit. During this final stage the water only moves through the UV portion of the treatment unit and then discharged to sea.



DEBALLASTING

Emptying

When ballast or de-ballasting events are completed, all valves to the treatment unit are closed. The drain assembly will open. All water in the treatment unit is removed to improve the environment for corrosion protection.

Treatment Unit Design

Trojan Marinex has developed a comprehensive product suite based on the integrated design and offers a full range of discrete flow models to minimize capital and installation costs. This eliminates the need to put many small systems together for large installed applications. The design of each discrete flow model has been optimized for the maximum flow and very challenging water quality conditions. Advanced tools such as Computational Fluid Dynamics and Intensity Models are utilized to optimize the design. These tools increase the efficiency of the overall system resulting in a reduction in environmental footprint. For example, the placement of the filter elements within the unit ensures laminar flow into the UV section of the treatment unit, which ensures proper exposure to the UV lamps for the most efficient disinfection treatment.

The treatment unit is designed to work with ballast pumps at a maximum working pressure of 6 bar. Working pressure of 6 bar typically exceeds the pressure rating of most vessel ballast water management systems.

The treatment unit including the mounting legs has been engineered and reviewed by third party finite element analysis (FEA) for pressure operation, structural analysis of the legs considering pitch, roll and heave. The treatment unit follows documented weld practices for to allow for repeatable weld quality.

Ultraviolet Intensity (UVI) Sensor

Every flow model is equipped with a UVI sensor to monitor the UV output of the lamps. In the event of low UV output, the system immediately triggers a cleaning cycle. If the condition is not resolved after a cleaning cycle an alarm condition is initiated to warn of the potential for insufficient treatment. The sensor that has been chosen follows a European standard for monitoring the intensity of the UV output.

Level Sensor

Every flow model is equipped with a level sensor. The level sensor is used to indicate water level conditions in the treatment unit. The level sensor acts as the primary safety indicator to prevent unwanted conditions in the treatment unit such as trapped air that can cause unwanted temperature conditions.

Pressure Sensor

Every flow model is equipped with two pressure sensors. One sensor is located on the inlet and the other sensor is located on the outlet of the treatment unit. These sensors work in conjunction to sense the differential pressure across the filtration system and act as a detection method for over pressurization. When the differential limit condition is met this triggers a filter cleaning sequence.

Temperature Sensor

Every flow model is equipped with a temperature sensor to monitor high temperature conditions. The temperature sensor provides a secondary means of safety (level sensor is primary) to prevent unwanted high temperature conditions.

Control cabinet

The control cabinet is home to electronic components that control the Ballast Water Treatment system. Some of the major components in this cabinet include; the programmable logic controller (PLC) and the human machine interface (HMI). The PLC is programmed with specific code to carry out the automated processes and monitoring functions. The HMI commonly referred to as a touch screen, allows access to various functions and settings, including automatic and manual controls. The touch screen serves as the systems monitoring window. An operator can view all aspects of operation and status at a glance. Additionally, the control cabinet can be interfaced with the ships SCADA system.

Power distribution cabinet

The power distribution cabinet houses main system power and breakers for distribution and protection of all system cabinets.

Lamp driver cabinet

The lamp driver cabinet is home to the lamp drivers that provide power to the lamp. The lamp driver footprint simplifies design and installation. The compact driver cabinets allow increased layout flexibility for installation in any location on board a vessel.

Each lamp driver contains advanced controls to maximize the lamp life. The lamp driver has high electrical efficiency (>95%) and reduces wasted energy and necessary cooling requirements. Each lamp driver has on-board digital signal processor to simplify diagnostics, improve reliability and improve the lamp life and UV output. Each driver comes equipped in a rack-mount design simplifying maintenance. Power and communication signals connect automatically when lamp driver is inserted – no manual wiring is required.

Pneumatic cabinet

The pneumatic cabinet provides distribution to all the valves.

Hydraulic cabinet

The hydraulic cabinet is home to the electric motor, pump, and hydraulic solenoid valves. The hydraulic connection points at the treatment unit are quick disconnection type.

Monitoring

The system automatically monitors and logs key components of the treatment process. This data must be stored for a 2 year period. The data logging will occur when the ballast water treatment system is operational or by-passed. Data is easily retrievable electronically via a CSV file.

Alarm Conditions

Equipment alarms have been broken into three categories. These alarms have been broken down into three categories.

Critical Alarms ~ Impact safety and operation of the vessel
Major Alarms ~ Impacts the operation of the ballast water treatment equipment.
Minor Alarm ~ Potential impact to the operation of the ballast water treatment system.

Safety Features

The UV portion of the treatment unit has safety features that have been developed to prevent personal injury:

- Lamp plug interlock - The design of the lamp sleeve assembly and lamp plug prevents a user from removing a UV lamp or a lamp sleeve assembly from the treatment unit while the lamp plug is connected to the UV lamp.
- Lamp plug disconnect - The electrical power supplied to a lamp plug is disconnected when the lamp plug is removed.
- Door limit switch - A limit switch removes power to the lamp drivers when the lamp driver cabinet door is opened.

Assembly & Manufacturing

Each treatment unit is pressure tested beyond its working pressure to ensure confidence in the designed working pressure in order to meet the assembly craftsmanship.

Each wiper drive cylinder is factory tested to ensure good working order.

2. System Information

General		
Treated Rated Capacity	500 m^3/h per unit	
Number of lamps	(48) Forty-eight	
Lamp Type	TrojanUV Solo Lamp™	
Sleeve cleaning	Automatic sleeve cleaning	
Lamp Power each (watt)	500	
Typical Electrical requirements	26.1 kVA	
Number of filters	(24) Twenty-four	
Minimum Flow Rate	50m^3/h	
Maximum Operating Pressure	6 bar	
Water temperature range	2°C to 40°C continuous (sea water) • No slush or ice	
Treatment Unit		
Material	316L stainless steel construction	
Filter information	1.5 bar minimum inlet pressure 0.05 bar pressure differential clean filter elements 0.25 bar pressure differential to start cleaning cycle	
Filter cleaning duration	Approximately 25 seconds per cleaning cycle.	
Filter cleaning frequency	Varies depending on the local water quality	
Lamp sleeve cleaning	Approximately 1 minute per cleaning cylinder	
Lamp cleaning cylinders	Three (3) magnetically coupled hydraulic cylinders	
Lamp cleaning frequency	At the start and end of every cycle and based on time	
Weight	Approx. 2,100 kg dry Approx. 3,200 kg wet	
Hydraulic connections	Ballasting inlet	Flange DN300 PN10
	De-ballasting inlet	Flange DN300 PN10
	Outlet	Flange DN300 PN10
	Backwash	Flange DN150 PN10
	Unit drain	Flange DN50 PN10
Installation orientation	Vertical	
Serviceability	Vertical ~ from the top	
Instrumentation	1 UVI Sensor, 5m cable length	
	1 Level sensor, 5m cable length	
	1 Temp sensor, 5m cable length	
	2 Pressure sensors (Inlet and outlet) 5m cable length	
UV		
Lamp type	TrojanUV Solo Lamp™	
Lamp power	500 watt / lamp	
Number of lamps	48	
Cleaning	Automatic sleeve cleaning is standard	
Drive cylinder qty	Three (3)	
Sleeve		
Sleeve type	Marine tube class	
Material	Quartz	
Length	1m	
End	Domed	
Holder	Flaired	
Sleeve wiper	standard	
Number of sleeves	Forty-eight (48)	

Filtration	
Number of filter elements	Twenty-four (24)
Filter material type	Super Duplex mesh
Sealing surface	EPDM O-ring
Tools required	No tools required to remove a filter
Filter Cleaning System	
Design	Upper and lower cleaning arm
Material	316L stainless steel
Control Cabinet	
Quantity	One (1) per treatment Unit
Configuration	Stand-alone cabinet
Dimensions (W x H x D)	800 mm x 1000 mm x 300 mm Wall mounted standard
Controller type	PLC with touch screen interface
Communication protocol	Ethernet/IP standard Modbus RS485
Electrical supply	240 V single phase, 2 wire (No Neutral) + GND, 50/60 Hz, 2.0 kVA
Max distance between control cabinet & lamp driver cabinet	Approx. 100 m standard (running distance)
Rating	IP54 standard
Materials	Powder coated mild steel standard
Weight	Approx. 65 kg
Programmable Logic Controller Type	M340 Modicon
Human Machine Interface Type	Modicon Magelis
Power distribution cabinet	
Electrical supply	240V, 3-phase, 3 wire (No Neutral) + GND, 50/60 Hz
Quantity	One (1) per system
Configuration	Stand-alone cabinet
Dimensions (W x H x D)	800 mm x 1000 mm x 300 mm Wall mounted standard
Weight	Approx. 64 kg
Rating	IP54 Standard
Materials	Powder coated mild steel standard
Lamp driver cabinet	
Common name	Lamp driver cabinet
Quantity	Two (2) per treatment unit (air or liquid cooled)
Configuration	Stand-alone cabinet
Dimensions (W x H x D)	600 mm x 620 mm x 600 mm (air cooled) Wall-mount standard
Cable length (running distance)	10 m standard
Communication Type	Modbus RS485 Communications
Driver cabinet weight	Approx. 80 kg (air cooled)
Local disconnect	Internal disconnect standard
Rating	IP54 standard
Number of drivers	Two cabinets with six (6) lamp drivers
Materials	Powder coated mild steel standard
Cooling	Air or Liquid cooled is available
Air Cooling Requirements	Clean, dry compressed air
	Approx. 140 CFM at 6 bar
Pneumatic Cabinet	
Quantity	One (1) per treatment unit
Configuration	Stand-alone cabinet

Dimension (W x H x D)	600 mm x 381.5 mm x 210 mm Wall-mount standard
Control Cable distance between treatment unit & cabinet (running distance)	20 m standard
Pneumatic hose rating	0 deg C to +80 deg C
Weight	Approx. 33 kg
Rating	IP54 standard
Materials	Powder coated mild steel standard
Air Supply Required	Varies depending on valves used and distance from cabinet.
Hydraulic Cabinet	
Quantity	One (1) per treatment unit
Configuration	Stand-alone cabinet
Dimension (W x H x D)	600 mm x 631 mm x 300 mm Wall-mount standard
Hydraulic Connection type	Quick disconnect at the treatment unit. Female BSPP at the cabinet
Hydraulic Cable length (running distance)	5 m standard
Hydraulic Cable rating	-40C to +100C Max working pressure 4775PSI (33MPa). Approved for hydraulic base fluids and lubricating oils
Hydraulic fluid type	TELUS T15
Weight	40kg
Rating	IP 54
Materials	Powder coated mild steel

AMENDMENT No. 1

Test Plan

Performance evaluation in land-based test facility. Trojan Marinex™ BWT 500 . April 2013.

2013.09.06

Amendment comments

Chapter 1.1 Background and objectives
It shall be stated that the test duration will not match the U.S. Coast Guard Standards (1 hour is stated in the ETV protocol) as this is not possible due to the size of the tanks available at the test facility. In this respect, the testing will deviate from the ETV Protocol.

Chapter 4.1 Technology performance claims – bullet 3
Revised text in italics:
Treatment rated capacity for one BWMS unit: 500 m^3/h *(measured as the net flow after the filter).*

Chapter 4.2 Technology and process description
Revised text in italics:

The technology and process description, including the appropriate sections of the format for the Technical Data Package described in Section 3.10 of the ETV protocol /4/, with safety and environmental hazards and precautions, *Controls Philosophy, P&ID* and photographs or drawings, is enclosed in the revised Appendix B.

Impact of Amendment

The Amendment is considered not to have any influence on the performance evaluation.

Preventive action

Not relevant.

Gitte I. Petersen

Project manager

2013.09.06

Date

Copy to be sent to the client, the Certification Body and the DHI Quality Assurance Unit.

Attachments:

- Comments received by DNV on the Test Plan

- Revised Appendix B including:
  - A revised version of the System Description
  - A copy of the Controls Philosophy
  - A copy of the P&ID for the system

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CANADA

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Org. No: NO 945 748 931 MVA

Your ref.:	Our ref.:	Date:
	TNANO386/CAPPEL/262.1-009316-J-27	2013-04-17

TROJAN TECHNOLOGIES,TROJAN UV BWMS, Id. No. 262.1-009316
Trojan Test Plan for Approval-Testing to begin Thursday April 18th

Reference is made to your letters dated 2013-04-18 and dated 2013-04-16. The following document is stamped 2013-04-17 and given the status as shown below:

Drawing No.	Rev.	DNV No.	Title	Code	Status
2013 DHI Test Plan		2	Test plan Land-based test		Appr.w/comm

	Drawing No. 2013 DHI Test Plan, "Test plan Land-based test" is approved, with the following comments:	Status
2	The system description describes UV lamp power regulation based on UV transmittance measured by a UV sensor. Please describe the regulation of the UV lamps in more detail. Please include also minimum UV intensisty the system will handle. The lowest UV intensity intended for the system must be tested during land-based testing. Please include reference to UV sensor location in details (technical drawing).	Pending
3	Please confirm that the flow is intended to meet is the net. flow after the filter.	Pending
4	Type and version of the control system. This must be specified. Handling and arrangement of the control system must be done according DNV Rules Pt.4 Ch.9. Please submit details for approval.	Pending
5	Please indicate how the warm up period will be applied at the DHI test facility. Will the valves be controlled automatically at the test facility? What is used for warm-up water?	Pending
6	Please confirm that the test is at least one hour. Ref. ETV Protocol 5.4.5	Pending
7	Limitations of the BWM system to be described	Pending
8	Please provide a PID for the system assembly	Pending

9	What is the LL UV-intensity that will trigger a cleaning cycle as described in "Ultraviolet Intensity (UVI) sensor in the SOP.	Pending
10	The SOP does not indicate what temperature is a high level set point and what the procedure is to avoid this during warm up and treatment.	Pending
11	DNV recommends Trojan Technology to organize their system description in the QAPP after the requirements set in USCG rules; § 162.060-38 Operation, Maintenance, and Safety Manual (OMSM).	For Inf.

Yours faithfully
for DET NORSKE VERITAS AS

Jad Mouawad
Head of Section
Environmental Protection

Andreas Cappelen
Contact Person

REVISED APPENDIX B

Description of the ballast water management system
as provided by the manufacturer

SYSTEM
DESCRIPTION

Trojan Marinex^{TM} BWT 500

Contents:

1. Process and equipment design

General description

Trojan Marinex^{TM} BWT 500 is a fully integrated Ballast Water Treatment System (BWTS) specifically designed for marine environments at a treated rated capacity 500 meters cube per hour. The system is unique in that it combines two purely physical treatment processes, both filtration, and UV disinfection in one single unit. Combining the treatment processes preserves a small footprint and increases the ability to locate the system within the vessel. Having combined the treatment processes in one single unit reduces the complex interconnecting piping and the associated pressure loss.

The system operation can be fully automated and integrated into a vessels ballasting system or can be managed separately through the controls of the ballast water treatment equipment.

The starting sequence of treatment occurs when the inlet valve is opened, allowing ballast water to enter. While the system starts filling the lamp initiation sequence is activated. Additionally, at the end of the filling cycle when the system is full the lamp wiper starts a cleaning cycle. Once the system is completely full the outlet valve is opened and the treatment process begins. The system control works together with a flow transmitter and the pump of the vessel.

Filtration is the first stage in the treatment process. Filtration removes particles and larger organisms, while evenly distributing the flow of the ballast water into the UV section of the treatment unit. Filtered water flows through the UV section of the treatment unit targeting all organisms not removed in the filtration process.

The final stage of the treatment process occurs during de-ballast. Previously treated water (filtered + UV) is moved from the ballast tank to the de-ballast inlet of the treatment unit. During this final stage the water only moves through the UV portion of the treatment unit and then discharged to sea.

The Trojan Marinex^{TM} BWT 500 consists of the following principal components;

<u>Treatment Unit</u>

- 316L stainless steel construction containing;
    - Twenty-four (24) super duplex custom designed filter elements for marine use.
    - Forty-eight (48) Low pressure high efficiency UV lamps (500 Watts each):
        - Using the TrojanUV Solo Lamp^{TM} Technology

- Automatic filter cleaning
- Automatic lamp cleaning
- One (1) UVI sensor
- One (1) Temperature sensor
- One (1) Level sensor
- Two (2) Pressure sensors (inlet & outlet)
- De-Aerators
- Drain assembly

Treatment Unit Cabinets

Power Distribution Cabinet
- Houses the main system power, and breakers.
- Distributes power to all components of the treatment system.

Control Cabinet
- Houses the PLC and other system control function components. The control switches and HMI are mounted on the door of the cabinet.

Lamp Driver Cabinet(s)
- Provides a clean environment for the lamp drivers and connection for all lamp cables.

Pneumatic Cabinet
- Contains all solenoid valves, and pneumatic controls for valves.

Hydraulic Cabinet
- Provides all required hydraulic components for the lamp cleaning system.

Note: All cabinets are wall mounted

Detailed Process Description

Filling

Depending on the mode of operation (ballast or deballast) the inlet or de-ballast inlet are opened to allow water to be moved into the treatment unit. Water can enter the system by gravity, with the ballast pump, and or an alternative filling pump. All other valves remain closed until the treatment unit is full, triggered by the level switch. While the treatment unit is full the lamp cleaning sequence is initiated. The duration of the filling sequence varies for each installation type and associated piping. When the system is full the outlet valve is opened and ballast water can begin to flow.

Automatic Lamp Cleaning System

Lamp cleaning initiates automatically. Typically cleaning sequence is initiated at the start of a filling sequence and at the end of a cycle. Ultraviolet lamps incorporated in all ballast water treatment systems are housed in quartz sleeves. These quartz sleeves can become fouled with debris on the sleeve surface reducing the amount of ultraviolet light available for treatment. The lamp cleaning system removes any fouling that could build up on the lamp sleeves. The lamp cleaning sequence is initiated automatically at the start and end of ballast or a de-ballast cycle and based on the time of operation. The system does not need to be stopped during a cleaning cycle.

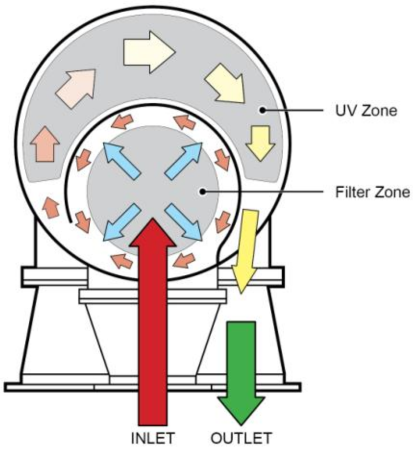
The automatic lamp cleaning system is sequentially driven. Each lamp wiping mechanism consists of a wiper plate, wiping seals and a drive cylinder. The drive cylinder moves the wiper plate with wiping seals from one end of the lamp sleeve to the other. A cleaning sequence consists of actuating the lamp cleaning system from its home position to the end of the lamp sleeves and back to the home position. The cleaning cycle is finished when the last lamp wiping mechanism reaches its home position. The benefit of having the cleaning process sequentially driven reduces disruption to flow and allows the ballasting or deballasting process to continue.

Each drive mechanism is magnetically coupled to a hydraulic drive cylinder. The drive cylinder is hermetically sealed to prevent the possibility of fluid loss. The carriage of the drive cylinder is home to the wiper plate and is magnetically coupled to the cylinder. All hydraulic connections are located on the outside of the treatment unit (non wetted area). Hydraulic fluid used to drive the cylinder ensures a smooth cleaning cycle.

Extensive development has gone into the design of the sleeve to support the lamp technology. Quartz is used as the sleeve material. Quartz is used in this application because it has a low thermal expansion, high thermal shock resistance, good dielectric properties, chemical inertness and good high temperature properties. Most importantly, it has a very high transmission of UV light.

Ballasting

The ballast sequence of treatment process occurs when the inlet valve is opened, allowing ballast water to enter the treatment unit. Filtration is the first stage in the treatment process. Filtration removes particles and targets larger organisms, while providing an evenly distributed flow of the ballast water into the UV section of the treatment unit. Filtered water flows through the UV section of the treatment unit targeting all organisms not removed in the filtration process. The treated water is directed to the ballast water tank through the ballast water outlet.



BALLASTING

Automatic Filter Cleaning System

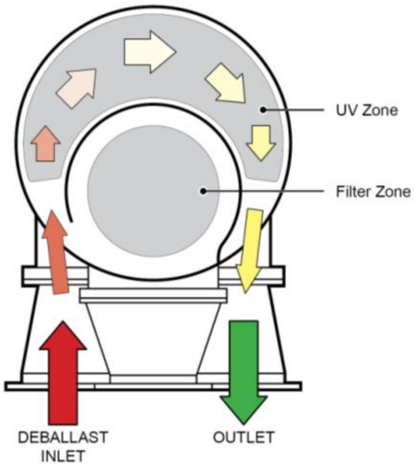
Each treatment unit is equipped with an automatic filter cleaning system. The cleaning system initiates when differential pressure is measured across the inlet and outlet of the ballast water treatment system. Each treatment unit has two pressure sensors, one located on the ballast water inlet and the other on the ballast water outlet. These pressure sensors provide a signal to the control panel to initiate a cleaning sequence. The cleaning sequence consists of opening an actuated backwash valve and signaling the filter drive motor to make one revolution. Each revolution of the drive motor allows each filter element to reverse its flow allowing accumulated debris trapped by the filter to be carried out to drain.

During the cleaning cycle, a flow meter is used in conjunction with a regulating valve to maintain consistent flow rate through the treatment unit. The treated rated capacity can be maintained while the system is in a filter cleaning cycle.

The cleaning system removes a filter from the process and allows filtered water to be diverted back across the filter removing trapped debris. The debris that is dislodged is then diverted back to its original source water. As each individual filter element is cleaned, the remaining filter elements continue to process water. Once the filter drive motor has completed its cycle, the backwash valve closes completing the cleaning sequence.

De-ballasting

The final stage of the treatment process occurs during de-ballast. Previously treated water (filtered + UV) is moved from the ballast tank to the de-ballast inlet of the treatment unit. During this final stage the water only moves through the UV portion of the treatment unit and then discharged to sea.



DEBALLASTING

Emptying

When ballast or de-ballasting events are completed, all valves to the treatment unit are closed. The drain assembly will open. All water in the treatment unit is removed to improve the environment for corrosion protection.

Treatment Unit Design

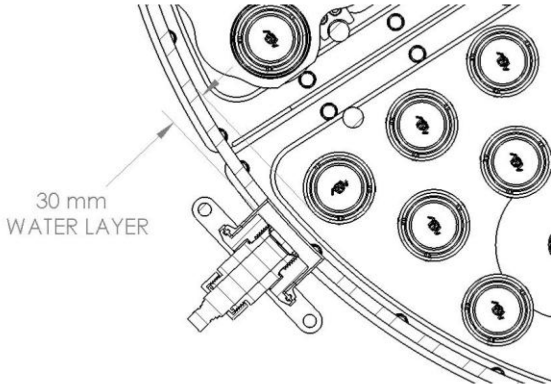
Trojan Marinex has developed a comprehensive product suite based on the integrated design and offers a full range of discrete flow models to minimize capital and installation costs. This eliminates the need to put many small systems together for large installed applications. The design of each discrete flow model has been optimized for the maximum flow and very challenging water quality conditions. Advanced tools such as Computational Fluid Dynamics and Intensity Models are utilized to optimize the design. These tools increase the efficiency of the overall system resulting in a reduction in environmental footprint. For example, the placement of the filter elements within the unit ensures laminar flow into the UV section of the treatment unit, which ensures proper exposure to the UV lamps for the most efficient disinfection treatment.

The treatment unit is designed to work with ballast pumps at a maximum working pressure of 6 bar. Working pressure of 6 bar typically exceeds the pressure rating of most vessel ballast water management systems.

The treatment unit including the mounting legs has been engineered and reviewed by third party finite element analysis (FEA) for pressure operation, structural analysis of the legs considering pitch, roll and heave. The treatment unit follows documented weld practices for to allow for repeatable weld quality.

Ultraviolet Intensity (UVI) Sensor

Every flow model is equipped with a UVI sensor to monitor the UV output of the lamps and ensure it remains above the threshold value. The threshold value for alarm purposes, will be determined during land-based testing and is defined as the minimum value observed over the required test cycles. In the event of low UV output, the system immediately triggers a cleaning cycle. If the condition is not resolved after a cleaning cycle, an alarm condition is initiated to warn of the potential for insufficient treatment. The sensor that has been chosen follows a European standard for monitoring the intensity of the UV output. The UVI sensor is installed to maintain a water later between the sensor and the UV lamp of 30mm in all models within the product suite. A schematic showing the sensor location is provided below.



Level Sensor

Every flow model is equipped with a level sensor. The level sensor is used to indicate water level conditions in the treatment unit. The level sensor acts as the primary safety indicator to prevent unwanted conditions in the treatment unit such as trapped air that can cause unwanted temperature conditions.

Pressure Sensor

Every flow model is equipped with two pressure sensors. One sensor is located on the inlet and the other sensor is located on the outlet of the treatment unit. These sensors work in conjunction to sense the differential pressure across the filtration system and act as a detection method for over pressurization. When the differential limit condition is met this triggers a filter cleaning sequence.

Temperature Sensor

Every flow model is equipped with a temperature sensor to monitor high temperature conditions. The temperature sensor provides a secondary means of safety (level sensor is primary) to prevent unwanted high temperature conditions.

Control cabinet

The control cabinet is home to electronic components that control the Ballast Water Treatment system. Some of the major components in this cabinet include; the programmable logic controller (PLC) and the human machine interface (HMI). The PLC is programmed with specific code to carry out the automated processes and monitoring functions. The HMI commonly referred to as a touch screen, allows access to various functions and settings, including automatic and manual controls. The touch screen serves as the systems monitoring window. An operator can view all aspects of operation and status at a glance. Additionally, the control cabinet can be interfaced with the ships SCADA system.

Power distribution cabinet

The power distribution cabinet houses main system power and breakers for distribution and protection of all system cabinets.

Lamp driver cabinet

The lamp driver cabinet is home to the lamp drivers that provide power to the lamp. The lamp driver footprint simplifies design and installation. The compact driver cabinets allow increased layout flexibility for installation in any location on board a vessel.

Each lamp driver contains advanced controls to maximize the lamp life. The lamp driver has high electrical efficiency (>95%) and reduces wasted energy and necessary cooling requirements. Each lamp driver has on-board digital signal processor to simplify diagnostics, improve reliability and improve the lamp life and UV output. Each driver comes equipped in a rack-mount design simplifying maintenance. Power and communication signals connect automatically when lamp driver is inserted – no manual wiring is required.

Pneumatic cabinet

The pneumatic cabinet provides distribution to all the valves.

Hydraulic cabinet

The hydraulic cabinet is home to the electric motor, pump, and hydraulic solenoid valves. The hydraulic connection points at the treatment unit are quick disconnection type.

Monitoring

The system automatically monitors and logs key components of the treatment process. This data must be stored for a 2 year period. The data logging will occur when the ballast water treatment system is operational or by-passed. Data is easily retrievable electronically via a CSV file.

Alarm Conditions

Equipment alarms have been broken into three categories.

Critical Alarms ~ Impact safety and operation of the vessel
Major Alarms ~ Impacts the operation of the ballast water treatment equipment.
Minor Alarm ~ Potential impact to the operation of the ballast water treatment system.

Safety Features

The UV portion of the treatment unit has safety features that have been developed to prevent personal injury:

- Lamp plug interlock - The design of the lamp sleeve assembly and lamp plug prevents a user from removing a UV lamp or a lamp sleeve assembly from the treatment unit while the lamp plug is connected to the UV lamp.
- Lamp plug disconnect - The electrical power supplied to a lamp plug is disconnected when the lamp plug is removed.
- Door limit switch - A limit switch removes power to the lamp drivers when the lamp driver cabinet door is opened.

Assembly & Manufacturing

Each treatment unit is pressure tested beyond its working pressure to ensure confidence in the designed working pressure in order to meet the assembly craftsmanship.

Each wiper drive cylinder is factory tested to ensure good working order.

2. System Information

General		
Treated Rated Capacity	500 m^3/h per unit	
Number of lamps	(48) Forty-eight	
Lamp Type	TrojanUV Solo Lamp™	
Sleeve cleaning	Automatic sleeve cleaning	
Lamp Power each (watt)	500	
Typical Electrical requirements	26.1 kVA	
Number of filters	(24) Twenty-four	
Minimum Flow Rate	50m^3/h	
Maximum Operating Pressure	6 bar	
Water temperature range	2°C to 40°C continuous (sea water) • No slush or ice	
Treatment Unit		
Material	316L stainless steel construction	
Filter information	1.5 bar minimum inlet pressure 0.05 bar pressure differential clean filter elements 0.25 bar pressure differential to start cleaning cycle	
Filter cleaning duration	Approximately 25 seconds per cleaning cycle.	
Filter cleaning frequency	Varies depending on the local water quality	
Lamp sleeve cleaning	Approximately 1 minute per cleaning cylinder	
Lamp cleaning cylinders	Three (3) magnetically coupled hydraulic cylinders	
Lamp cleaning frequency	At the start and end of every cycle and based on time	
Weight	Approx. 2,100 kg dry Approx. 3,200 kg wet	
Hydraulic connections	Ballasting inlet	Flange DN300 PN10
	De-ballasting inlet	Flange DN300 PN10
	Outlet	Flange DN300 PN10
	Backwash	Flange DN150 PN10
	Unit drain	Flange DN50 PN10
Installation orientation	Vertical	
Serviceability	Vertical ~ from the top	
Instrumentation	1 UVI Sensor, 5m cable length	
	1 Level sensor, 5m cable length	
	1 Temp sensor, 5m cable length	
	2 Pressure sensors (Inlet and outlet) 5m cable length	
UV		
Lamp type	TrojanUV Solo Lamp™	
Lamp power	500 watt / lamp	
Number of lamps	48	
Cleaning	Automatic sleeve cleaning is standard	
Drive cylinder qty	Three (3)	
Sleeve		
Sleeve type	Marine tube class	
Material	Quartz	
Length	1m	
End	Domed	
Holder	Flaired	
Sleeve wiper	standard	
Number of sleeves	Forty-eight (48)	

Filtration	
Number of filter elements	Twenty-four (24)
Filter material type	Super Duplex mesh
Sealing surface	EPDM O-ring
Tools required	No tools required to remove a filter
Filter Cleaning System	
Design	Upper and lower cleaning arm
Material	316L stainless steel
Control Cabinet	
Quantity	One (1) per treatment Unit
Configuration	Stand-alone cabinet
Dimensions (W x H x D)	800 mm x 1000 mm x 300 mm Wall mounted standard
Controller type	PLC with touch screen interface
Communication protocol	Ethernet/IP standard Modbus RS485
Electrical supply	240 V single phase, 2 wire (No Neutral) + GND, 50/60 Hz, 2.0 kVA
Max distance between control cabinet & lamp driver cabinet	Approx. 100 m standard (running distance)
Rating	IP54 standard
Materials	Powder coated mild steel standard
Weight	Approx. 65 kg
Programmable Logic Controller Type	M340 Modicon
Human Machine Interface Type	Modicon Magelis
Control Version	Vijeo Designer Runtime Version 6.0.3.142 Vijeo Designer Version 6.0.3
Power distribution cabinet	
Electrical supply	240V, 3-phase, 3 wire (No Neutral) + GND, 50/60 Hz
Quantity	One (1) per system
Configuration	Stand-alone cabinet
Dimensions (W x H x D)	800 mm x 1000 mm x 300 mm Wall mounted standard
Weight	Approx. 64 kg
Rating	IP54 Standard
Materials	Powder coated mild steel standard
Lamp driver cabinet	
Common name	Lamp driver cabinet
Quantity	Two (2) per treatment unit (air or liquid cooled)
Configuration	Stand-alone cabinet
Dimensions (W x H x D)	600 mm x 620 mm x 600 mm (air cooled) Wall-mount standard
Cable length (running distance)	10 m standard
Communication Type	Modbus RS485 Communications
Driver cabinet weight	Approx. 80 kg (air cooled)
Local disconnect	Internal disconnect standard
Rating	IP54 standard
Number of drivers	Two cabinets with six (6) lamp drivers
Materials	Powder coated mild steel standard
Cooling	Air or Liquid cooled is available
Air Cooling Requirements	Clean, dry compressed air
	Approx. 140 CFM at 6 bar
Pneumatic Cabinet	

Quantity	One (1) per treatment unit
Configuration	Stand-alone cabinet
Dimension (W x H x D)	600 mm x 381.5 mm x 210 mm Wall-mount standard
Control Cable distance between treatment unit & cabinet (running distance)	20 m standard
Pneumatic hose rating	0 deg C to +80 deg C
Weight	Approx. 33 kg
Rating	IP54 standard
Materials	Powder coated mild steel standard
Air Supply Required	Varies depending on valves used and distance from cabinet.
Hydraulic Cabinet	
Quantity	One (1) per treatment unit
Configuration	Stand-alone cabinet
Dimension (W x H x D)	600 mm x 631 mm x 300 mm Wall-mount standard
Hydraulic Connection type	Quick disconnect at the treatment unit. Female BSPP at the cabinet
Hydraulic Cable length (running distance)	5 m standard
Hydraulic Cable rating	-40C to +100C Max working pressure 4775PSI (33MPa). Approved for hydraulic base fluids and lubricating oils
Hydraulic fluid type	TELUS T15
Weight	40kg
Rating	IP 54
Materials	Powder coated mild steel

CONTROLS PHILOSOPHY -

Project # DHI DENMARK

1. GENERAL

The objective of this document is to provide details regarding the control strategy for the Trojan Marinex Ballast Water Treatment system. The controls philosophy outlines the major hardware components, system status, alarm conditions and the modes of operation of the UV system.

Acronyms and Abbreviations

DNV:	Det Norske Veritas
GUI:	Graphical User Interface
HC:	Hydraulic Cabinet
HMI:	Human Machine Interface
IEC:	International Electrotechnical Commission
LDC:	Lamp Driver Cabinet
N.C.	Normally Closed
N.O.:	Normally Closed:
OS:	Operating System
PC:	Pneumatic Cabinet
PDC:	Power Distribution Cabinet
PLC:	Programmable Logic Controller
SCADA:	Supervisory Control and Data Access
CC:	Control Cabinet
TU:	Treatment Unit
UV:	Ultra Violet
UVI:	Ultra Violet Intensity
UVT:	Ultra Violet Transmittance

PLC Layout

The following is the list of PLC hardware included in the Control Cabinet.

1.01.1 Rack I/O Configuration: Base 8 Slot (BMX XBP 0800)

SLOT NUMBER	PART NUMBER	DESCRIPTION
0	BMX CPS3020	Power Supply, 24Vdc
1	BMX P342020	M340 Processor w/ Ethernet and Modbus RS485 ports
2	BMX NOC0401	M340 Ethernet Communication Module, 4 port
3	BMX DDI1602	M340 Digital Input Module, 16 point
4	BMX DDI1602	M340 Digital Input Module, 16 point
5	BMX DDI1602	M340 Digital Input Module, 16 point
6	BMX AMM0600	M340 Combine Analog Module, 4 I/P CH, 2 O/P CH
7	BMX DDO1602	M340 Digital Output Module, 16 point
8	BMX DDO1602	M340 Digital Output Module, 16 point

***Note: RS485 communications to the system (LDC) will be connected via port 2.**

1.01.2 Remote Rack I/O Configuration for Models 500 and greater

SLOT NUMBER	PART NUMBER	DESCRIPTION
0	STB NIP 2212	STB Advantys NIM Ethernet Module
1	STB PDT 3100K	STB Advantys Power Module, 24Vdc
2	STB DDI 3725KS	STB Advantys Digital Input Module, 16 point
3	STB DDI 3725KS	STB Advantys Digital Input Module, 16 point
4	STB DDO 3705KS	STB Advantys Digital Output Module, 16 point
5	STB DDO 3705KS	STB Advantys Digital Output Module, 16 point

1.01.3 HMI

Operator Interface	Schneider Magelis 5.4 Colour Touch Screen – XBTGT2310

I/O Layout

1.01.4 Slot 2 – Discrete Input Card

Ch.	Function	P&ID Tags	I/O State
0	Start PB	N.O.	ON – PB Press
1	Stop PB	N.C.	OFF – PB Press
2	Reserved (Remote Start PB)	N.O.	

3	Reserved (Remote Stop PB)	N.C.	
4	Ballast Mode Selected	N.O.	ON – Ballast process
5	De-Ballast Mode Selected	N.O.	ON – De-Ballast process
6	Spare		
7	Emergency Stop	N.C.	ON – E-Stop cct OK
8	Treatment Unit Level SW	LSL-1100	ON – Level OK
9	Treatment Unit temperature SW	TSH-1100	ON – Temp OK
10	Local/Remote	N.O.	ON – Remote mode selected
11	Control cabinet MCR	N.O.	ON – Safeties OK
12	Backwash Valve Opened	ZSO-1102	ON – Valve Open
13	Backwash Valve Closed	ZSC-1102	ON – Valve Closed
14	Test Lights PB	N.O.	ON – All O/P lights turn ON
15	Cabinet Surge Protection	N.O.	ON – Surge Protection OK

1.01.5 Slot 3 – Discrete Input Card

Ch.	Function	Normal State	I/O State
0	Ballast Pump Feedback	XS-1102	ON – Pump Running
1			
2			
3			
4			
5			
6			
7	Drain Flow SW		ON – Drain Flow present
8	Ballast Valve Open FV1003 Open	ZSO-1000	ON - Valve Open
9	Ballast Valve FV1003 Closed	ZSC-1000	ON - Valve Closed
10	De-Ballast Valve FV1004 Open	ZSO-1001	ON - Valve Open
11	De-Ballast Valve FV1004 Closed	ZSC-1001	ON - Valve Closed
12	Bypass Valve FV1081 Open	ZSO-1001	ON - Valve Open
13	Bypass Valve FV1081 Closed	ZSC-1001	ON - Valve Closed
14	Outlet Valve FCV1080Open	ZSO-1200	ON - Valve Open
15	Outlet Valve FCV1080Closed	ZSC-1200	ON - Valve Closed

1.01.6 Slot 4 – Discrete Input Card

Ch.	Function	Normal State	I/O State
0	Wiper Drive Pressure Switch	PS-1400	ON - Cylinder End Travel

1	Wiper#1 Extended	ZS-1400A	ON - Wiper fully Extended
2	Wiper#2 Extended	ZS-1400B	ON - Wiper fully Extended
3	Wiper#3 Extended	ZS-1400C	ON - Wiper fully Extended
4	Spare Input		
5	Spare Input		
6	Spare Input		
7	Spare Input		
8	LDC#1 Door Open	N.O.	ON - Door Closed
9	LDCl#1 Hi Temp Warning 49°C	N.C.	ON - Temperature OK
10	LDC#1 Contactor feedback	N.O.	ON - Contactor Closed
11	LDC#1 Hi Temp Shutdown 60°C	N.C.	ON - Temperature OK
12	Spare Input		
13	Spare Input		
14	Hydraulic Cabinet Door SW	N.O.	ON – Door Closed
15	Silent Alarm Buzzer	N.O.	ON - Buzzer OFF

1.01.7 Slot 5 – Analog Card Combined Input and Output

Ch.	Function	Normal State	I/O State
0	Flow	4-20mA	4mA = 0 m³/hr, 20mA = 650
1	UV Intensity	4-20mA	4mA = 0, 20mA = 10.0 mW/cm²
2	Ballast (Inlet) Pressure	4-20mA	4mA = 0bar, 20mA = 10bar
3	Outlet Pressure	4-20mA	4mA = 0bar, 20mA = 10bar
0	Outlet Valve Control	4-20mA	4mA = Closed, 20mA = Fully Open
1	Spare Analog Output	4-20mA	4mA = , 20mA =

1.01.8 Slot 6 – Discrete Output Card

Ch.	Function	Normal State	I/O State
0	Major Alarm		ON - Major alarm notification
1	Minor Alarm		ON - Minor alarm notification
2	System Run		ON - System Run notification
3	Ballasting Light (Amber)		ON - System is ballasting
4	De-Ballasting Light (Amber)		ON - System is de-ballasting
5	System ON Light (Green)		ON - Power/operational
6	Alarm Buzzer On		ON - Sound audible alarm
7	Fault Light (Red)		ON – System fault
8	Green Stack Light		ON – System OK
9	Yellow Stack Light		ON – System Warning/Info

10	Red Stack Light		ON – System fault
11	Spare O/P		
12	Spare O/P		
13	LDC#1 Main Contactor		ON - Contactor Closed
14	LDC#1 ON Pilot Light		ON - Driver Panel Energized
15	LDC#1 Vortex Air Supply Solenoid		ON - Valve Opens

1.01.9 Slot 7 – Discrete Output Card

Ch.	Function	Normal State	I/O State
0	Wiper Extend	YS-1400A	ON - Wiper Extends
1	Wiper Retract	YS-1400B	ON - Wiper Retracts
2	Wiper#1 Solenoid	YS-1401A	ON – Wiper#1 operates
3	Wiper#2 Solenoid	YS-1401B	ON – Wiper#2 operates
4	Wiper#3 Solenoid	YS-1401C	ON – Wiper#3 operates
5	Spare		
6	Backwash Valve	FV-1910	ON - Valve Opens
7	Treatment Unit Drain Valve		ON - Valve Opens, pump runs
8	Ballast Inlet Valve	FV-1003	ON - Valve Opens
9	Spare O/P		
10	De-Ballast Inlet Valve	FV-1004	ON - Valve Opens
11	Spare O/P		
12	Wiper Motor	P-1400	ON - Wiper Motor runs
13	Spare O/P		
14	Outlet Valve FCV1200	FCV-1080	ON - Valve Opens (Proportional controlled)
15	Filter Cleaning Motor	M191	ON - Motor Runs for 25sec

Remote I/O for Power Distribution Cabinet

1.01.10 Remote I/O Slot 2 – Discrete Input Card

Ch.	Function	Normal State	I/O State
0	Spare		
1	Spare		
2	Test Lights PB		ON – All O/P lights turn ON
3	Spare		
4	Spare		
5	Spare		
6	Spare		
7	Emergency Stop		ON – System ok
8	Spare		

9	Power Distribution Cabinet MCR		ON – Contactor closed
10	Spare		
11	Spare		
12	Spare		
13	Spare		
14	Reserved – Sludge Pump Feedback		ON – Pump running
15	Cabinet Surge Protection		ON - ok

1.01.11 Remote I/O Slot 3 – Discrete Input Card

Ch.	Function	Normal State	I/O State
0	Driver Cabinet#1 Door Open		ON – Door Closed
1	Driver Cabinet#1 Hi Temp Warning 49°C		ON – Temperature ok
2	Driver Cabinet#1 Contactor Feedback		ON – Contactor Closed
3	Driver Cabinet#1 Hi Temp Alarm 60°C		ON – Temperature ok
4	Driver Cabinet#2 Door Open		ON – Door Closed
5	Driver Cabinet#2 Hi Temp Warning 49°C		ON – Temperature ok
6	Driver Cabinet#2 Contactor Feedback		ON – Contactor Closed
7	Driver Cabinet#2 Hi Temp Alarm 60°C		ON – Temperature ok
8	Spare		
9	Spare		
10	Spare		
11	Spare		
12	Spare		
13	Spare		
14	Spare		
15	Spare		

1.01.12 Remote I/O Slot 4 – Discrete Output Card

Ch.	Function	Normal State	I/O State
0	Driver Cabinet#1 Main Contactor		ON – Contactor Closed
1	Driver Cabinet#1 ON Pilot Light		ON – Driver Cabinet Energized
2	Driver Cabinet#2 Main Contactor		ON – Contactor Closed
3	Driver Cabinet#2 ON Pilot Light		ON – Driver Cabinet Energized
4	Reserved		
5	Reserved		
6	Reserved		

7	Reserved		
8	Filter Cleaning Motor	M-1100	ON - Motor Runs for 25sec
9	Light Stack Indicator – Green		ON - System OK
10	Light Stack Indicator – Yellow		ON - System Warning Alarm
11	Light Stack Indicator – Red		ON - System Critical/Major Alarm
12	Driver Cabinet#1Vortex Air Cooler		ON – Valve Opens
13	Driver Cabinet#2Vortex Air Cooler		ON – Valve Opens
14	Reserved		
15	Reserved		

1.01.13 Remote I/O Slot 5 – Discrete Output Card

Ch.	Function	Normal State	I/O State
0	Alarm Buzzer		ON – Alarm sounds
1	Spare		
2	Spare		
3	Spare		
4	Spare		
5	Spare		
6	Spare		
7	Spare		
8	Spare		
9	Spare		
10	Spare		
11	Spare		
12	Spare		
13	Spare		
14	Spare		
15	Spare		

Ballast Water Treatment Equipment Configurations

The following parameters were used to configure the Ballast Water Treatment Equipment

ITEM	CONFIGURATION	DESCRIPTION
No. of Lamps per TU	14 24 48 62 84	150 250 500 750 1000

	110 124	1250 1500
No. of Lamp Driver Cabinets:	1 2 3 4	150, 250 500, 750 1000 1250, 1500
No. Of Control and Power Distribution Cabinets	1	For 150 & 250 only, One per Treatment Unit
No. of Control Cabinet	1	Models 500 and greater One per Treatment Unit
No. of Power Distribution Cabinets	1	Models 500 and greater One per Treatment Unit
No. of Hydraulic Cabinets	1	One per Treatment Unit
Number of Wipers per Treatment Unit	1 2 3 4 6	150 250 500, 750 1000 1250, 1500
Ballast Inlet Valve Present	Yes	Open/Closed
De-Ballast Inlet Valve Present	Yes	Open/Closed
Outlet Valve Present	Yes	Proportional, Analog 4-20mA
Backwash Valve	Yes	Open/Closed
Drain Valve Present	Yes	Open/Closed
Drain Pump	Yes	Runs when Drain Valve Opens
LAN:	Monitor	
PLC IP Address:	200.200.200.200	1 Ethernet Port, 1 Modbus RS485 Port
HMI IP Address:	200.200.200.201	Ethernet IP
HMI Language:	English	
NOC (4 ports)	200.200.200.202	Ethernet IP
Remote I/O (NIP)	200.200.200.211	Ethernet IP for 500 and Greater
Custom SCADA	Customer specific	Ethernet IP
Lamp Driver Communication	Modbus RS485	Baud Rate 38400
Lamp Driver Addresses: LDC1	SW 10x - 1, SW 1x – 1 to 8	See Wire diagrams
Lamp Driver Addresses: LDC2	SW 10x - 2, SW 1x – 1 to 8	See Wire diagrams
Lamp Driver Addresses: LDC3	SW 10x - 3, SW 1x – 1 to 8	See Wire diagrams
Lamp Driver Addresses: LDC4	SW 10x - 4, SW 1x – 1 to 8	See Wire diagrams
No. of High Temperature Sensors per TU:	1	
No. of Level Sensors per TU:	1	
No. of UV Intensity Sensors per TU:	1	
UVI Measurement Type:	Analog	Current 4-20mA
Flow Measurement Type:	Analog	Current 4-20mA
Flow Setpoint per TU		Model Dependent

Max over Flow Per TU:	20m³/hr	
Ballast Pressure Measurement Type:	Analog	Current 4-20mA
Outlet Pressure Measurement Type:	Analog	Current 4-20mA
Differential Pressure Setpoint	0.25Bar	Ballast Pressure – Outlet Pressure

Safety Features

The Marinex control strategy employs a minimum of equipment protection interlocks but does monitor a number of alarm conditions that will result in control action designed to maintain treatment and protect the equipment and personnel.

The system has Critical alarms that will shutdown the system completely.

The first critical interlock conditions that will shutdown the Trojan Marinex™ BWT System is the E-stop circuit. When pressed all UV lamps are de-energized, power is removed from the Lamp Driver Cabinets and all valves will close. The alarm controls an electrical interlock that removes power from all lamp drivers when the alarm is active. The alarm input is wired directly to the PLC for alarm purposes in the control system. The alarm will disable the automatic wiping functionality and filter cleaning. .

The second critical alarm condition is the Treatment Unit Level switch. When a low water level is detected during the treatment process, the UV lamps are de-energized and a Low Water Alarm is indicated. The Low Water Level alarm will close all valves plus disable the automatic wiping functionality and filter cleaning.

The third critical alarm condition is a High Temperature alarm. When the temperature goes above 60°C, the UV lamps are de-energized and a High Temperature alarm is indicated. The High Temperature alarm will close all valves, disable the automatic wiping and filter cleaning. The system will not be able to restart unit the temperature cools to 50°C.

Certain other alarm conditions will trigger a control action that may result in lamps being de-energized. These alarm conditions are more fully described later in this document.

2. CONTROL SYSTEM OVERVIEW

The Trojan Marinex™ BWT System combines filtration and UV disinfection in a single treatment unit. This combination reduces the need for complex interconnecting piping and the associated pressure loss. The small footprint of the integrated system increases flexibility in locating the system within the vessel.

The operation of the system is fully automated. Once the treatment inlet valve is opened and the system is filled with water the UV Lamp Sleeve Cleaning system initiates a cleaning cycle and simultaneously the UV Lamps begin the Warm-up sequence. Once the Lamp Warm-up is complete the outlet valve is modulated open to achieve the designed flow and the treatment process starts. The system control works together with the flow signal and the pump to maintain desired flow-rate.

When ballasting, filtration is the first step in the process removing particles and larger organisms, while evenly distributing the flow of the ballast water into the UV section of the treatment unit. The second stage of the process occurs during de-ballast. Treated water is moved from a ballast tank to the de-Ballast Inlet of the treatment unit, bypassing the filter system, and moves through the UV section of the treatment unit and is then discharged overboard.

Control Cabinet

The Control Cabinet includes the host controller of the Trojan Marinex™ BWT System, controlling only one Treatment unit. It consists of a Modicon M340 PLC Controller with associated I/O modules, an Operator Interface (HMI) and related electrical components. The Control Cabinet is combined with the Power Distribution Cabinet in the 150 and 250 models. The Control Cabinet connects to the Power Distribution Cabinet's via Ethernet, Lamp Driver Cabinet through a RS-485 network and remote I/O. A ship SCADA network maybe optionally connected to the Control Cabinet through a Modbus network protocol and will be able to access designated read and write integer arrays. The Control Cabinet also provides power and protection to the Hydraulic Cabinet.

The Operator Interface (HMI) allows the users to access the Trojan Marinex™ BWT System through the following functions:

- System settings
- Operation and status indication of:
    - System Overview
    - Lamps
    - Lamp Drivers
    - Wiper Groups
    - Valves
- Alarming
- Trending and data logging
- Online help
- System Clock

The PLC Controller provides the following functions:

- Process parameter measurement
    - UV Intensity (UVI)
    - Flow
    - Inlet and Outlet pressure
    - Pressure differential
    - TU Low Water Level
    - TU High Temperature
- Communications to PDC
- SCADA communications (if available)

PLC Fault Conditions

The following table summarizes all of the available PLC controller alarms:

Alarm	Description	Alarm Delay	Mask Other Alarms When Active	Control Action In Remote Auto
PLC Fault	A PLC controller/module fault exists.	None	None	PLC faults out

Power Distribution Cabinet (PDC)

The Power Distribution Cabinet houses the components used to power the Control Cabinet, Lamp Driver Cabinet, and the Hydraulic Cabinet. The Power Distribution Cabinet monitors the control I/O to each Lamp Driver Cabinet. The Power Distribution Cabinet performs the following functions:

- Control Cabinet main power
- Lamp Driver Cabinet main power and control I/O
- Power Distribution Cabinet protection

Communications

The Control Cabinet communicates to the Lamp Driver Cabinet via Modbus RTU through RS-485 network. The RS-485 network is split inside the Control Cabinet to each of the Lamp Driver Cabinet's via Repeater's. Repeaters are used to reduce communications issues, (i.e. Voltage drops) to each Lamp Driver Cabinet.

The PLC communicates to the Control Cabinet HMI via Ethernet I/P.

Communication to the Remote I/O module in the Power Distribution Cabinet (for models 500 and greater) is via Ethernet I/P.

If applicable, communications to a remote HMI is via Ethernet I/P

System Pairs	Device	I/P Address		Comments
		Starboard(odd)	Port(Even)	
1st System Pair	Processor	200.200.100.10	200.200.200.10	
	HMI	200.200.100.11	200.200.200.11	
	NOC	200.200.100.12	200.200.200.12	
	Remote I/O	200.200.100.13	200.200.200.13	
	LDC1	200.200.100.14	200.200.200.14	Reserve for future
	LDC2	200.200.100.15	200.200.200.15	
	LDC3	200.200.100.16	200.200.200.16	
	LDC4	200.200.100.17	200.200.200.17	
2nd System Pair	Processor	200.200.100.110	200.200.200.110	
	HMI	200.200.100.111	200.200.200.111	
	NOC	200.200.100.112	200.200.200.112	
	Remote I/O	200.200.100.113	200.200.200.113	
	LDC1	200.200.100.114	200.200.200.114	Reserve for future
	LDC2	200.200.100.115	200.200.200.115	
	LDC3	200.200.100.116	200.200.200.116	
	LDC4	200.200.100.117	200.200.200.117	
3rd System Pair	Processor	200.200.100.210	200.200.200.210	
	HMI	200.200.100.211	200.200.200.211	

	NOC	200.200.100.212	200.200.200.212	
	Remote I/O	200.200.100.213	200.200.200.213	
	LDC1	200.200.100.214	200.200.200.214	Reserve for future
	LDC2	200.200.100.215	200.200.200.215	
	LDC3	200.200.100.216	200.200.200.216	
	LDC4	200.200.100.217	200.200.200.217	

System Alarm Conditions

The Marinex BWT system is subject to a number of alarm conditions, which may be a minor, major or critical in nature. All alarms are subject to a minor, major, critical or individually configured alarm delay timers. The following table depicts alarm structure; these alarms are described further in subsequent sections:

Alarm Severity	Definition of Severity and Impact on the System	Description of Alarm
Critical	Indicates that immediate attention is required. The Marinex BWT system shut down until the fault is cleared. Alarms may be latched and require a reset from the Operator Interface after the alarm condition is remedied.	- LDC High Temperature Shutdown - TU High Temperature shutdown - TU Low Water Level - Estop
Major	Indicates that immediate attention is required, otherwise damage may occur or disinfection performance may be compromised. The Marinex BWT system does not shutdown. It continues to operate at the maximum disinfection achievable.	System Alarms - Lamp Driver Cabinet Door Open - Low UV Intensity - Low Flow Alarm - Flow Meter Fault - PLC Fault
Minor	Indicates that the Marinex BWT requires maintenance but it is operating in compliance. Alarms are not latched and no reset is required. No other actions will be taken.	System Alarms - Lamp Failure - Lamp Driver Failure - Lamp Driver Communication Failure - Lamp Lifetime Exceeded - Valves not in Auto - System Flow Exceeded

Security

The Control Cabinet HMI will be configured with security access restrictions according the three different access levels defined in the table below.

Level	User	Description of Access	User Name
1	Operator	User may view all unrestricted data and enter process data, control process equipment and adjust process control set points	OP
2	Maintenance	User has access to configuration of process control strategies and displays	OP1
3	Technician	Complete access to all system functions	OEM

3. TROJAN MARINEX™ BWT SYSTEM OPERATION MODES

Control Architecture

The control system architecture has been designed such that each Trojan Marinex™ BWT System in the vessel will be controlled by a separate PLC. Each Treatment Unit consists of filters and rows of lamps. The lamp drivers monitor and control up to four (4) UV lamps each. Lamp drivers are connected through a RS-485 communication link to the Control Cabinet. Both the lamp and driver status information is passed back to the Control Cabinet via the RS-485 link. The PLC processor in the control cabinet communicates directly with the lamp drivers.

All Lamp Driver Cabinets communicate with the PLC to accept commands and exchange status information.

Treatment Unit Process Modes

There are 2 possible operational modes that a Trojan Marinex™ BWT System can be placed into: "Ballast" and "De-Ballast"

Ballast Mode

The Trojan Marinex™ BWT System is in the off condition until the operator has selected Ballast mode and presses the Start PB (or initiated remotely). The system checks all safeties and ensures all valves are Closed to the system. Any Alarms that are initiated must be acknowledged. With all Alarms cleared, the Trojan Marinex™ BWT System is in a Ready Mode. The lamp driver cabinets are energized and the Vortex AC Coolers activated. The De-Ballast Influent (FV1003) and System By-Pass (FV1081) valves Must Be Closed throughout the Ballast process.

When the ship Pump ON Signal is received, the Trojan Marinex BWT System starts to open the Ballast Inlet Valve (FV1003). Ballast water will enter the Trojan Marinex BWT system through the Filter Chamber and then into the UV Lamp section. The Ballast Inlet valve (FV1003) will continue to open until the Valve Open position switch is activated. The TU Outlet Valve (FCV1080) must remain Closed until the Low Level switch is closed (N.O. Switch, fail safe wiring).

When the Low Level Switch is Closed (treatment unit full), the UV Lamps are energized in sequence. A Lamp Sleeve Cleaning cycle is activated. After the lamp warm up period is achieved, the Outlet Valve (FCV1080) starts to Open. The Trojan Marinex BWT System is now in Treatment mode.

The TU Outlet Valve (FCV1080) is a proportional control valve. The valve is controlled by a PID loop via the system flow meter. The system flow rate is preset during installation to meet the ships process requirement and must not exceed the treatment unit rated capacity as per IMO certification. The proportional valve adjusts until the system flow rate is achieved and maintained.

The flow will continue until the Ballast process is completed. Throughout the process, if the Treatment Unit Differential Pressure is >0.25 Bar (HMI setpoint), the system will initialize a Filter Cleaning cycle (See Filter Cleaning Logic). The filter cleaning cycle will Stop when the sequence is completed and the treatment unit Differential Pressure is < 0.15 Bar (HMI setpoint).

When the ballast process is completed, the operator presses the Stop pushbutton or the ships system transmits a Stop signal to the Trojan Marinex™ BWT System which enters into a shutdown procedure. The Treatment Unit outlet valve (FCV1200) will start to close. The Filter Cleaning logic runs when the Treatment Unit outlet valve (FCV1200) is closing. When the Filter Cleaning is completed, the Ballast Inlet valve (FV1000) starts to close. The ships ballast pump is turned OFF. The UV Lamps are de-energized once the Ballast Inlet and Treatment outlet (FV1000, FCV1200) valves are Closed or the Low Level Switch Opens (no alarm in this case).

The Lamp Driver cabinets will remain on. There is a lamp driver cabinet cool down period (5 minutes) that allows the lamp drivers to cool. After the lamp driver cabinet cool down period, the Vortex A/C cooler is turned OFF

After the Ballast Inlet and Treatment Unit outlet valves (FV1000, FCV1200) are Closed, a Lamp Sleeve Cleaning cycle is initiated (See Lamp Sleeve Cleaning description). When the Lamp Sleeve Cleaning cycle is complete, the Treatment Unit drain valves open to drain the remaining water out from the system. Upon completion, the drain valves close and the Trojan Marinex BWT System returns to the off mode.

De-Ballast Mode

The Trojan Marinex BWT System is in the off Mode until the operator has selected De-Ballast mode and presses the Start pushbutton (or remote operation). The system checks all safeties and ensures all valves are Closed to the system. Any Alarms that are initiated must be acknowledged. With all Alarms cleared, the Trojan Marinex BWT System is in a Ready Mode. The lamp driver cabinets are energized and the Vortex AC Coolers activated. The Ballast Inlet (FV1003) and System By-Pass (FV1081) valves Must Be Closed throughout the De-Ballast process.

When the ship Pump ON Signal is received, the Trojan Marinex BWT Equipment starts to open the De-Ballast Inlet valve (FV1004). Ballast water will enter the Trojan Marinex BWT system through the UV Lamp section thus by-passing the Filter Chamber. The De-Ballast Inlet valve (FV1004) will continue to open until the Valve Open position switch is activated

The Treatment Unit outlet Valve (FCV1080) must remain Closed until the Low Level switch is closed (N.O. Switch, fail safe wiring). When the Low Level Switch is Closed, the UV Lamps are energized in sequence. A Lamp Sleeve Cleaning cycle is activated. After the lamps warm up period is achieved, the Treatment Unit outlet Valve (FCV1080) starts to Open. The Trojan Marinex BWT Equipment is now in Treatment mode.

The Treatment Unit outlet Valve (FCV1080) is a proportional control valve. The valve is controlled by a PID loop via the system flow meter. The system flow rate is preset during installation to meet the ships process requirement and must not exceed the Trojan Marinex BWT Equipment treated rated capacity (IMO Certification). The proportional valve will continue to open and adjust until the system flow rate is achieved and maintained.

When de-ballasting is completed, the operator presses the Stop push button or the ships system transmits a Stop signal to the Trojan Marinex BWT equipment which enters into a shutdown procedure. The De-Ballast Inlet and treatment unit outlet valve (FV1004, FCV1080) will close. When the De-Ballast Inlet and treatment unit outlet valves (FV1004, FCV1080) are closed, the ship ballast pump is turned off. The UV lamps are de-energized when the valves are closed or the Low Level Switch Opens (no alarm in this case).

The Lamp Driver Cabinet’s will remain on. There is a LDC cool down period (5 minutes) that allows the lamp drivers to cool. After the lamp driver cabinet cool down period, the Vortex A/C cooler is turn OFF.

After the De-Ballast Inlet and Treatment Unit Outlet valves (FV1004, FCV1080) are Closed, a Lamp Sleeve Cleaning cycle is initiated (See Lamp Sleeve Cleaning description). When the Lamp Sleeve Cleaning cycle is completed, the Trojan Marinex BWT System drain valves are Open to remove the remaining water from the system. Upon completion, the drain valves close and the Trojan Marinex BWT System returns to the off mode.

“System By-Pass Mode - Process”

The Trojan Marinex BWT System can be completely By-passed during emergency situation, complete system failure, mid-ocean ballast adjustment for fuel consumption, etc. The system By-pass operation will be fully controlled by the ship either manual or via the ships main SCADA/Computer system.

The Trojan Marinex BWT System will remain in the off Mode. A System By-Pass Signal is received by the Trojan Marinex BWT System, the system will automatically record the Date and Time (used by port authorities).

The ships Control system will Open the System By-Pass Valve (FV1081) and all other valves related to the Trojan Marinex BWT equipment must be closed. The pump on signal with not valves open on the treatment equipment will be recorded as a bypass event.

Treatment Unit Alarms

The following table summarizes all of the available Treatment Unit alarms:

Alarm	Description	Alarm Delay	Mask Other Alarms When Active?	Control Action In Remote Auto
Lamp Failure	One or more lamps have failed.	Minor	None	None
Multiple Lamp Failure	Number of failed lamps has reached or exceeded Multiple Lamp Failure Setpoint.	Major	None	TU Not OK bit set
Lamp Lifetime Exceeded	One or more of the lamps in the system have exceeded the lamp lifetime set point.	Minor	None	None
Treatment Unit High Temperature	Treatment Unit temperature above set point	Critical		Control Cabinet will turn off the lamp drivers, TU Not OK bit is set
Treatment Unit Low Level	Treatment unit not full	Critical		Control Cabinet will turn off the lamp drivers, TU Not OK bit is set
Lamp Driver Failure	Indicates a Lamp Driver(s) has failed.	Minor	None	None
Lamp Driver Communication Failure	Indicates a communication failure between the Control Cabinet and lamp driver(s).	Minor	None	None
LDC High Temperature Shut Down	The LDC temperature has increased beyond the high limit.	Critical	None	Control Cabinet will turn off the lamp drivers, TU Not OK bit is set

Filter Cleaning Failing-Water Quality Issues	More than 3 attempts to backwash	Major		None
Valves Not in Auto	Inlet, Outlet, Backwash, not in auto	Minor		None
Low UV Intensity	Intensity below set point	Major		None
Emergency Stop	Emergency Stop Pressed	Critical		Control Cabinet will turn off the lamp drivers, TU Not OK bit is set

4. FILTER CLEANING

Control Architecture

The 500 Filter is integrated with the Treatment Unit. Throughout the Ballast Process only, the water pressure is measured on both the influent and effluent pipes of the Treatment Unit. The pressure for each device is displayed on the HMI in bars. A differential pressure is calculated from the two pressure transmitters:

Inlet Pressure Transmitter – Outlet Pressure Transmitter = System Pressure Differential

The calculated System Pressure Differential is displayed on the HMI in bars.

The Filter Cleaning Cycle is activated when the differential pressure across the UV Housing is > 0.25 bar (HMI setpoint) for a set period of time (de-bounce). The backwash valve is opened, and the filter cleaning motor is turned on. Each filter element is backwashed individually thus to minimize the impact to the ships ballast water process. The filter cleaning cycle is approximately 25 seconds (adjustable).

The Filter Cleaning process is completed when the system differential pressure is approximately < 0.15 bar (HMI Setpoint). If the differential pressure is > 0.15 bar, then the cleaning cycle starts over. If the cleaning process occurs more than 3 times (an indication of harbor water issues), a warning alarm is activated and the Filter Cleaning Process continues to operate until the differential pressure is < 0.15bar.

When the Ballast process is completed (operator presses Stop pushbutton), the filters are cleaned. A Filter Cleaning cycle is activated when the effluent valve is Closed.

5. SLEEVE CLEANING (WIPER)

Control Architecture

The sleeve cleaning will occur when a Ballast or De-Ballast process is initiated and completed or when an adjustable timer has been completed (configurable).

When a ballasting or de-ballasting process is initiated by the operator and the Treatment Unit Level switch is ON, a sleeve cleaning is executed. The sleeve cleaning is executed sequentially through the wiper groups.

Wiper groups that are not enabled will not be executed. Each wiper group must complete a cycle before the next starts. The wipers clean approximately 16 lamp sleeves per group. When a ballasting or de-ballasting process is complete and both the Ballast Inlet and Outlet valves are closed, a Lamp Sleeve Cleaning cycle is executed.

When a wiper sequence is in Extend, the travel time to activate the Wiper Extended sensor takes approximately 25seconds (adjustable). When the wiper is fully extended, the solenoid de-energizes waits to 2 seconds then energizes the retract solenoid. The retract solenoid is energized for approximately 25seconds or when the hydraulic pressure switch is activated.

After each wiper has been cycled, the system waits for the next cleaning occurrence.

Sleeve Cleaning (Wiper) Control Modes

The following table further summarizes the available control modes:

Mode	Wiping Controlled By	Wiper Action
Wipe- Auto	PLC	Automatic sequence initiated for all enabled wipers.
Wipe – Manual Extend	PLC	Individual wipers are Extended by operator selection via HMI
Wipe – Manual Retract	PLC	Individual wipers are Retracted by operator selection via HMI
Wipe – Manually Initiated	PLC	One wiper cycle sequence initiated for all enabled wiper by operator via HMI.

6. FLOW INPUT SIGNAL

A flow signal is required for the automatic control of the system. The flow signal is used in the PID that controls the Treatment Unit proportional Outlet valve to ensure the flow does not exceed the certified value according to IMO certification. The Flow is displayed in m^3/hr.

Flow Measurement Modes

Analog Flow Signal

A 4-20mA analog flow signal is brought in through the PLC analog input card and scaled to a configurable engineering units range. The raw signal counts are passed through a signal scaling routine to convert to the configured engineering units' value, and then passed through a de-bouncing filter routine.

The operator cannot manually override the flow from the System Overview screen. A minor alarm will be posted to indicate that the flow meter has faulted.

Flow Fault Conditions

The following table summarizes all of the available flow alarms:

Alarm	Description	Alarm Delay	Mask Other Alarms When Active	Control Action In Remote Auto

Low Flow	Flow is below preset Setpoint	Enterable		
Flow Meter Fault	4-20 mA flow signal input is below 2mA or above 20.5mA	Major	None	
Low Flow – Out of Validation Range	Check Validation Range mode only – Flow is below Low Flow Validation Range Setpoint	Minor	None	None
High Flow – Out of Validation Range	Check Validation Range mode only – Flow is above High Flow Validation Range Setpoint	Major	None	Run the system at full capacity for disinfection.

7. UV INTENSITY INPUT

A UV Intensity signal is provided for Treatment Unit. The signal originates from a 4-20 mA sensor mounted on the side wall of the Treatment Unit and terminated at the Control Cabinet.

Intensity Fault Conditions

The following table summarizes all of the available intensity alarms:

Alarm	Description	Alarm Delay	When Active Will Mask Other Alarms	Control Action In Remote Auto
Low UV Intensity Warning	Measured Intensity below UVI Warning Setpoint after warm-up.	Minor	None	None
Low UV Intensity	Measured Intensity below UVI Alarm Setpoint after warm-up.	Major	None	None

8. BALLAST AND OUTLET PRESSURE

When the system is in Ballast mode, the Ballast Inlet Pressure and the Outlet pressure signal is provided from the Treatment Unit to the Control Cabinet. The signal originates from a 4-20 mA pressure transmitters mounted on the Ballast Inlet pipe and the Outlet pipe of the Treatment Unit

Pressure Measurement Modes

The measured Pressures are used in the calculation of the pressure differential across the Treatment Unit and are displayed on the HMI. The 4-20mA analog pressure signals are brought in through the PLC analog card and scaled to a configurable engineering units range. The raw signal counts are passed through a signal scaling routine to convert to the configured engineering units' value and then passed through de-bouncing filter routine. The scaled values will be represented in "Bar"

Pressure Fault Conditions

The following table summarizes all of the available pressure and differential pressure alarms:

Alarm	Description	Alarm Delay	When Active Will Mask Other Alarms	Control Action In Remote Auto
High inlet Pressure Warning	Measured pressure above the sys tem requirements.	Minor	None	None
Pressure Transmitter Fault	4-20 mA pressure signal input is below 2mA or above 20.5mA	Major	None	None

9. VESSEL SCADA INTERFACE

SCADA Interface Architecture

The system template can optionally provide a selection of data which is available to the vessel SCADA system to allow remote monitoring of the Marinex BWT Equipment. The PLC will act as a slave node only and will not initiate any communication messaging or data transfers, but will respond to polling messages on the required network address. SCADA information will be available in a selection of contiguous 16-bit integer addresses as defined in the data table shown in the following sections. A minimal amount of data will also be able to be transferred from a SCADA system to the PLC in order to allow limited remote control functions.

SCADA interface protocols that are available as standard options are listed in the specific Control Software specification documents for individual PLC platforms.

SCADA Fault Conditions

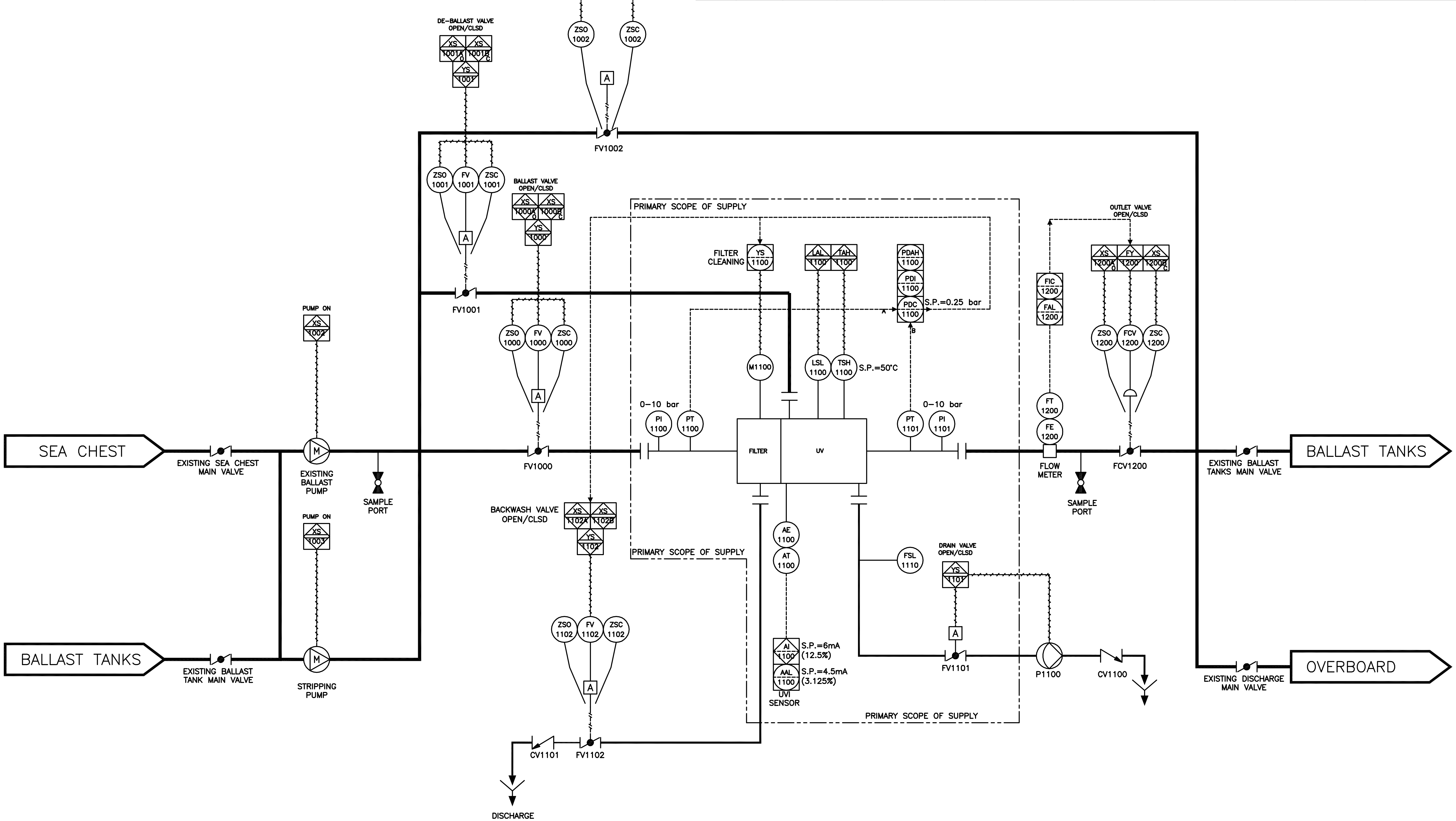
The following table summarizes all of the available SCADA alarms:

Alarm	Description	Alarm Delay	Mask Other Alarms When Active	Control Action In Remote Auto
SCADA Fault	The Vessel SCADA network has stopped communication with the PLC.	20 sec	None	

Revision History

Rev	Description	Rev By	Date
1.0	Initial Revision		

MARINEX - TREATMENT UNIT TABLE											
STANDARD UNIT										ATEX UNIT (ADDERS TO STANDARD UNIT)	
NAME	INLET	DEBALLAST	OUTLET	BACKWASH	DRAIN	FLOW SET POINT (m^3/hr)	LOW FLOW SET POINT (m^3/hr) "FAL1200"	DRAIN VALVES FV1101	AIR VAC/REL VALVES	LEVEL SWITCH LSL1100A/B	TEMPERATURE SWITCH TSH1100A/B
150	DN150	DN150	DN150	DN150	DN50	150	50	2	4	2	2
250	DN200	DN200	DN200	DN150	DN50	250	50	3	5	2	2
500	DN300	DN300	DN300	DN150	DN50	500	50	6	7	2	2
750	DN400	DN400	DN400	DN150	DN50	750	50	5	6	2	2
1000	DN400	DN400	DN400	DN150	DN50	1000	50	6	8	2	2
1250	DN500	DN500	DN500	DN200	DN50	1250	50	8	9	2	2
1500	DN600	DN600	DN600	DN200	DN50	1500	50	7	10	2	2



A	RELEASED	–	BAD	–	–	–
REV	REVISION DESCRIPTION	LOG NO.	REV'D BY	CHK'D BY	APPRV'D BY	DATE YYYY-MM-DD

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS TOLERANCES: 2 PL DEC ± N/A 3 PL DEC ± N/A ANGLE DEG ± N/A REMOVE ALL BURRS ALL CORNERS R 0.010 OR BREAK CD – CRITICAL CHARACTERISTIC

TROJAN marinex

DESCRIPTION: STANDARD MARINEX TREATMENT UNIT P&ID

THIRD ANGLE PROJECTION

10.0mm ON ORIGINAL DWG

SCALE: N/A

DWG NO. MX0057

REV A

SHEET 1 OF 1

SIZE D

APPENDIX B

Revised adjustments, service and maintenance log for Trojan Marinex™ BWT 500 during land-based testing

Adjustment and service log related to Trojan Marinex BWT 500 BWMS during land based test – April 2013 to July 2013 at DHI test facility in Hundested, Denmark.

CMI: Celina Isen (Trojan)
JAM: John Mascunana (Trojan)
SB: Shaun Bullen (Trojan)
MP: Matt Porebski (Trojan)
LT: Lacie Tunks (Trojan)
GL: Glen Latimer (Trojan)
MJA: Michael Jacob Andersen (DHI)
JOH: Jørgen Hansen (DHI)
FK: Flemming Koefoed (DHI)
GIP: Gitte Ingelise Petersen (DHI)
CAH: Camilla Hedberg (DHI)

Date	Event	Any actions taken	Maintenance Type	Present from Trojan	Present from DHI
2013.04.18	During DNV inspection, it was noted that it was not possible to determine the power consumption during testing.	Trojan hired an electrician to reinstall the Candura power consumption logger (2013.04.22). Trojan on site to fix the Candura power consumption logger (2013.04.24).	*Test equipment maintenance	CMI	GIP, FK
2013.05.02	Lamp failure alarm during startup of system	Lamp #33 and #34 replaced due to lamp alarm.	Marinex system maintenance	CMI	CAH, FK
2013.05.21	Lamp inspection	Inspected all lamps and sleeves for moisture. None found.	Inspection	JAM LT	FK, MJA
2013.05.21	Lamp cleaning alarm	Replaced proximity switch spring (proximity switch indicates when wiper has reached top of sleeves)	Marinex system maintenance	JAM LT	FK, MJA
2013.27.05	Software update	A minor software revision was performed to display the UV Intensity Sensor reading in engineering units (mW/cm2). Prior to this change, the sensor reading was displayed in %, defined as a percentage of the full-scale value (100 mW/cm2).	Marinex system maintenance	SB MP GL JAM	FK

2013.05.30	Flush motor failure upon startup of system	Diagnostics indicated that an overload setting on the flush motor was set too low. The overload was reset to the proper setting which solved the problem and the test was resumed. The incorrect setting was suspected to be a result of the system not being returned to its' proper setting following the Factory Acceptance Test that was performed on May 29th.	Marinex system maintenance	SB MP GL JAM	FK, MJA
2013.07.10	New source water pump installation	A new source water pump was installed to provide better pressure and flow to demonstrate effective operation at > 500 m^3/hr.	*Test equipment maintenance	MP	FK
2013.07.11	Following the test, it was determined that the flow meter used in controlling the Marinex system was not reading accurately resulting in a low flow test (below 500 m3/h)	The Marinex system was temporarily set to receive the control flow signal from the DHI flow meter. Later it was confirmed that the original flow meter was reading accurately. No further action was taken and subsequent tests were conducted with the same flow meter which was confirmed to be reading accurately using several methods.	*Test equipment inspection	MP	FK

* Test equipment maintenance refers to maintenance performed on peripheral equipment that is part of the testing setup and is not part of the Trojan Marinex Ballast Water Treatment system.

APPENDIX C

Data logging from the biological efficacy testing with Trojan Marinex™ BWT 500

Table C.1 Biological test cycle data logging (B-1)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Salinity (PSU)	19
Retention tank No.	C1
Test cycle No.	B-1
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae (*Tetraselmis* sp.)
System cleaned before ballast	Yes
Date and time ballast start	2013.04.18 11:05
Date and time ballast stop	2013.04.18 11:33
Flow rate during ballast (average)	544 m^3/h
Flow rate to ballast tank (calculated)	465 m^3/h
Power consumption during ballast*	As the power analyzer was not working properly for the first two tests, no power consumption was logged
UV intensity*	6.1 mW/cm^2
Treated volume during ballast	214 m^3 (+ 3 m^3 for sampling)
Volume used for ballasting (approx.)	261 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.04.23 11:16
Date and time de-ballast stop	2013.04.23 11:37
Flow rate during discharge (average)	546 m^3/h
Power consumption during de-ballast*	As the power analyzer was not working properly for the first two tests, no power consumption was logged
UV intensity*	7.7 mW/cm^2
Treated volume during de-ballast	195 m^3
General comments/operational issues	Brief alarm on backflush 2013.04.18 11:10 acknowledged and operation continued. Detailed online monitoring data available in enclosed data files.

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table C.2 Onsite measurements (B-1) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	109 (±1.4)	7.9 (±0.00)	19 (±0.00)	8.4 (±0.06)	31 (±1.0)
TM BWT 500 inlet (T0)	110 (±1.8)	7.8 (±0.01)	19 (±0.00)	8.0 (±0.01)	31 (±0.75)
TM BWT 500 1st treatment (T0)	110 (±1.8)	8.0 (±0.00)	19 (±0.02)	8.2 (±0.04)	37 (±1.6)
TM BWT 500 1st treatment (T5)	86 (±2.7)	7.7 (±0.00)	19 (±0.02)	8.8 (±0.10)	11 (±3.2)
TM BWT 500 2nd treatment (T5)	87 (±2.4)	7.8 (±0.01)	19 (±0.05)	8.9 (±0.12)	10 (±1.7)
Control discharge (T5)	69 (±2.5)	7.5 (±0.03)	19 (±0.00)	9.8 (±0.40)	4.6 (±1.0)

PSU Practical salinity units
NTU Nephelometric turbidity units

Table C.3 Biological efficacy test cycle data logging (B-2)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Salinity (PSU)	19
Retention tank No.	B1
Test cycle No.	B-2
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae (*Tetraselmis* sp.)
System cleaned before ballast	Yes
Date and time ballast start	2013.04.18 12:36
Date and time ballast stop	2013.04.18 13:05
Flow rate during ballast (average)	535 m^3/h
Flow rate to ballast tank (calculated)	447 m^3/h
Power consumption during ballast*	As the power analyzer was not working properly for the first two tests, no power consumption was logged
UV intensity*	6.2 mW/cm^2
Treated volume during ballast	213 m^3 (+ 3 m^3 for sampling)
Volume used for ballasting (approx.)	266 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.04.23 13:06
Date and time de-ballast stop	2013.04.23 13:28
Flow rate during discharge (average)	545 m^3/h
Power consumption during de-ballast*	As the power analyzer was not working properly for the first two tests, no power consumption was logged
UV intensity*	7.7 mW/cm^2
Treated volume during de-ballast	200 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table C.4 Onsite measurements (B-2) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	109 (±1.4)	7.9 (±0.00)	19 (±0.00)	8.4 (±0.06)	31 (±1.0)
TM BWT 500 inlet (T0)	111 (±0.09)	7.9 (±0.01)	19 (±0.00)	8.3 (±0.03)	30 (±0.70)
TM BWT 500 1st treatment (T0)	110 (±2.3)	8.0 (±0.01)	19 (±0.02)	8.3 (±0.06)	38 (±3.6)
TM BWT 500 1st treatment (T5)	81 (±0.60)	7.7 (±0.01)	19 (±0.00)	9.5 (±0.27)	11 (±2.7)
TM BWT 500 2nd treatment (T5)	83 (±1.4)	7.7 (±0.02)	19 (±0.02)	9.5 (±0.27)	10 (±0.81)
Control discharge (T5)	69 (±2.5)	7.5 (±0.03)	19 (±0.00)	9.8 (±0.40)	4.6 (±1.0)

PSU Practical salinity units
NTU Nephelometric turbidity units

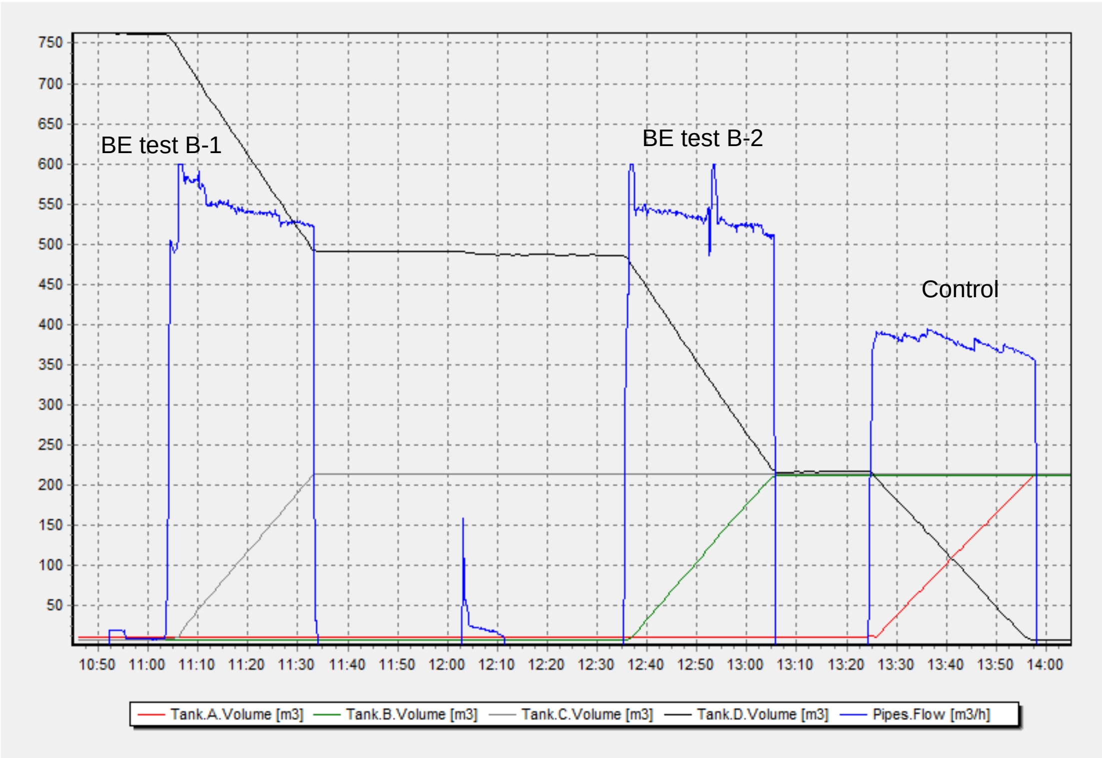


Figure C.1 Biological efficacy test cycles B-1 and B-2 data plot. Ballast operation

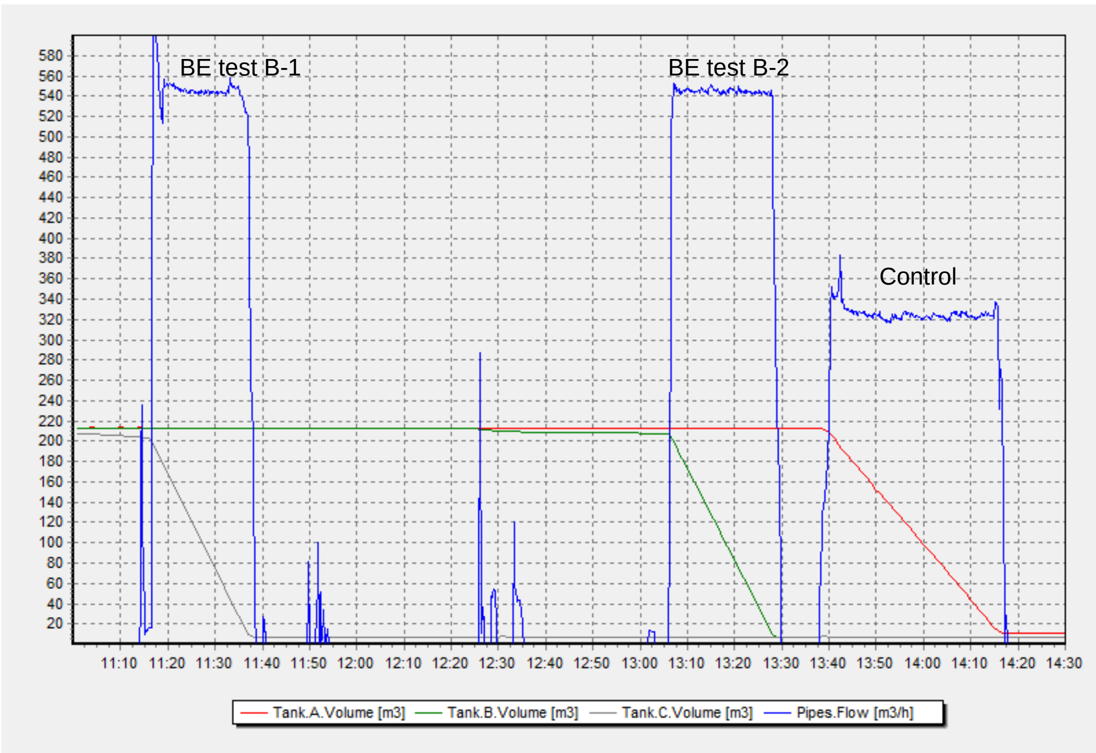


Figure C.2 Biological efficacy test cycles B-1 and B-2 data plot. De-ballast operation

Table C.5 Biological efficacy test cycle data logging (B-3)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Salinity (PSU)	18
Retention tank No.	C1
Test cycle No.	B-3
Use of cultured/harvested organisms	Addition of backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae (*Tetraselmis* sp.)
System cleaned before ballast	Yes
Date and time ballast start	2013.06.20 8:34
Date and time ballast stop	2013.06.20 9:02
Flow rate during ballast (average)	572 m^3/h
Flow rate to ballast tank (calculated)	484 m^3/h
Power consumption during ballast*	26.64 kWh + 17.67 kWh for cooling power**
UV intensity*	5.7 mW/cm^2
Treated volume during ballast	215 m^3 + 3 m^3
Volume used for ballasting (approx.)	261 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.06.25 11:09
Date and time de-ballast stop	2013.06.25 11:30
Flow rate during discharge (average)	507 m^3/h
Power consumption during de-ballast*	26.58 kWh + 17.67 kWh for cooling power**
UV intensity*	6.9 mW/cm^2
Treated volume during de-ballast	192 m^3
General comments/operational issues	Manual valve on backwash piping closed to see if flow rate through filter and UV unit would increase. Valve was reopened again when flow rate did not increase. Flow rate slowly decreased throughout the ballast operation.

* Information on manufacturer-specified parameters and power consumption data provided by the client

** *Note from Trojan: Air-cooled version was used for land-based testing primarily due to ease of installation for testing purposes.*

Table C.6 Onsite measurements (B-3) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	98 (±0.51)	8.3 (±0.0016)	18 (±0.0022)	18 (±0.020)	32 (±0.46)
TM BWT 500 inlet (T0)	97 (±0.17)	8.3 (±0.0032)	18 (±0.00)	18 (±0.014)	32 (±0.70)
TM BWT 500 1st treatment (T0)	99 (±0.60)	8.2 (±0.012)	18 (±0.070)	18 (±0.058)	31 (±6.5)
TM BWT 500 1st treatment (T5)	36 (±2.2)	7.5 (±0.080)	19 (±0.0047)	18 (±0.34)	11 (±0.88)
TM BWT 500 2nd treatment (T5)	39 (±1.9)	7.6 (±0.027)	18 (±0.0086)	19 (±0.28)	13 (±1.2)
Control discharge (T5)	19 (±4.4)	7.3 (±0.057)	19 (±0.0050)	19 (±0.34)	0.15 (±0.16)

PSU Practical salinity units
NTU Nephelometric turbidity units

Table C.7 Biological efficacy test cycle data logging (B-4)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Salinity (PSU)	18
Retention tank No.	B1
Test cycle No.	B-4
Use of cultured/harvested organisms	Addition of backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae (*Tetraselmis* sp.)
System cleaned before ballast	Yes
Date and time ballast start	2013.06.20 10:04
Date and time ballast stop	2013.06.20 10:37
Flow rate during ballast (average)	493 m^3/h
Flow rate to ballast tank (calculated)	390 m^3/h
Power consumption during ballast*	26.66 kWh + 17.67 kWh for cooling power**
UV intensity*	5.7 mW/cm^2
Treated volume during ballast	205 m^3 + 3 m^3
Volume used for ballasting (approx.)	267 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.06.25 12:33
Date and time de-ballast stop	2013.06.25 12:56
Flow rate during discharge (average)	510 m^3/h
Power consumption during de-ballast*	26.58 kWh + 17.67 kWh for cooling power**
UV intensity*	6.9/7.0 mW/cm^2
Treated volume during de-ballast	185 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files

* Information on manufacturer-specified parameters and power consumption data provided by the client
** *Note from Trojan: Air-cooled version was used for land-based testing primarily due to ease of installation for testing purposes.*

Table C.8 Onsite measurements (B-4) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	98 (±0.51)	8.3 (±0.0016)	18 (±0.0022)	18 (±0.020)	32 (±0.46)
TM BWT 500 inlet (T0)	98 (±0.052)	8.3 (±0.0050)	18 (±0.00)	18 (±0.0076)	32 (±1.0)
TM BWT 500 1st treatment (T0)	99 (±0.60)	8.2 (±0.0049)	18 (±0.049)	18 (±0.013)	32 (±5.0)
TM BWT 500 1st treatment (T5)	32 (±1.1)	7.5 (±0.033)	19 (±0.00)	19 (±0.24)	13 (±2.1)
TM BWT 500 2nd treatment (T5)	35 (±2.0)	7.6 (±0.029)	18 (±0.031)	19 (±0.24)	13 (±1.4)
Control discharge (T5)	19 (±4.4)	7.3 (±0.057)	19 (±0.0050)	19 (±0.34)	0.15 (±0.16)

PSU Practical salinity units
NTU Nephelometric turbidity units

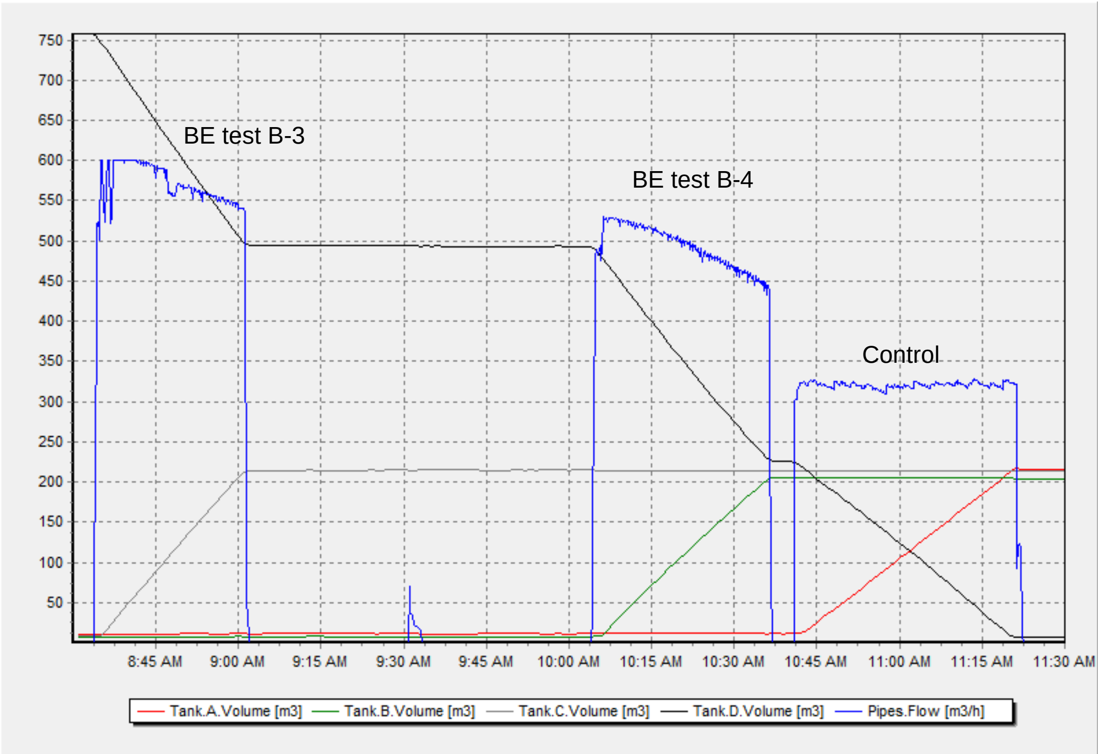


Figure C.3 Biological efficacy test cycles B-3 and B-4 data plot. Ballast operation

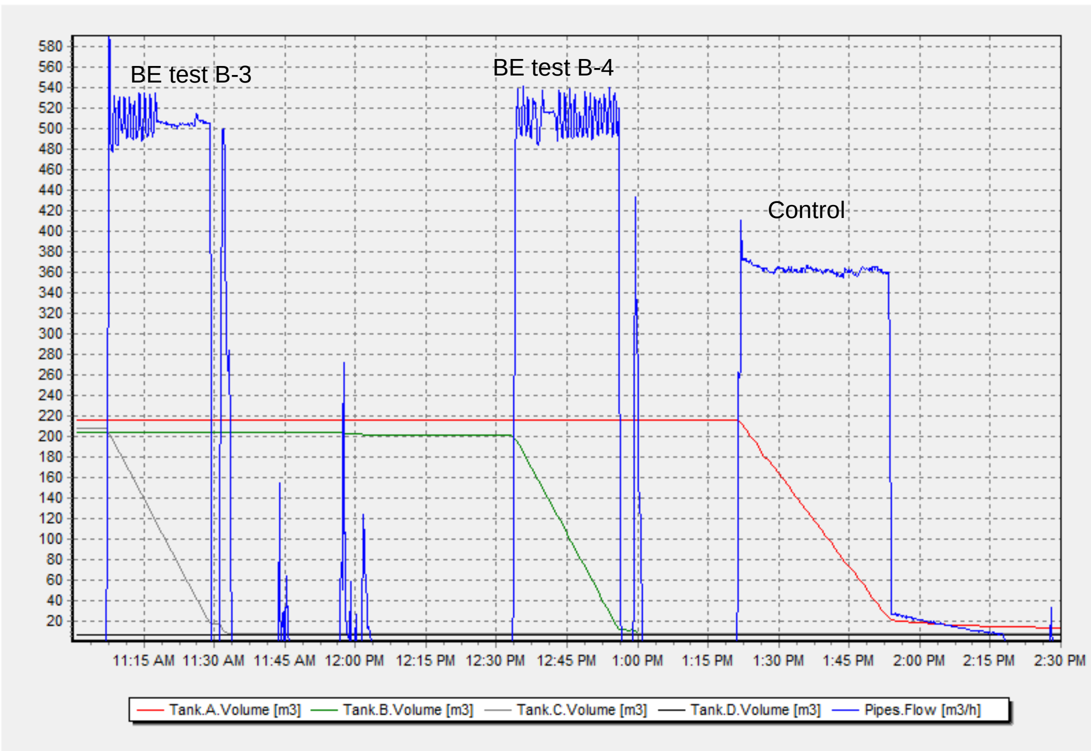


Figure C.4 Biological efficacy test cycles B-3 and B-4 data plot. De-ballast operation

Table C.9 Biological efficacy test cycle data logging (B-5)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Salinity (PSU)	17
Retention tank No.	C1
Test cycle No.	B-5
Use of cultured/harvested organisms	Addition of backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae (*Tetraselmis* sp.)
System cleaned before ballast	Yes
Date and time ballast start	2013.06.27 09:13
Date and time ballast stop	2013.06.27 09:41
Flow rate during ballast (average)	514 m^3/h
Flow rate to ballast tank (calculated)	464 m^3/h
Power consumption during ballast*	26.75 kWh + 17.87 kWh for cooling power**
UV intensity*	5.6 mW/cm^2
Treated volume during ballast	206 m^3 + 3 m^3
Volume used for ballasting (approx.)	241 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.07.02 9:12
Date and time de-ballast stop	2013.07.02 9:31
Flow rate during discharge (average)	510 m^3/h
Power consumption during de-ballast*	26.6 kWh + 17.87 kWh for cooling power**
UV intensity*	7.5-7.6 mW/cm^2
Treated volume during de-ballast	172 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files

* Information on manufacturer-specified parameters and power consumption data provided by the client

** *Note from Trojan: Air-cooled version was used for land-based testing primarily due to ease of installation for testing purposes.*

Table C.10 Onsite measurements (B-5) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	95 (±0.095)	8.0 (±0.00)	18 (±0.0027)	17 (±0.041)	36 (±1.1)
TM BWT 500 inlet (T0)	96 (±0.58)	8.0 (±0.0051)	18 (±0.0083)	17 (±0.19)	40 (±4.0)
TM BWT 500 1st treatment (T0)	98 (±1.9)	8.0 (±0.011)	17 (±0.030)	17 (±0.018)	42 (±8.0)
TM BWT 500 1st treatment (T5)	26 (±0.44)	7.4 (±0.021)	18 (±0.00)	16 (±0.088)	6.3 (±0.40)
TM BWT 500 2nd treatment (T5)	29 (±1.2)	7.5 (±0.014)	17 (±0.0069)	16 (±0.076)	7.6 (±0.30)
Control discharge (T5)	15 (±0.53)	7.3 (±0.022)	18 (±0.0045)	17 (±0.29)	1.7 (±0.24)

PSU Practical salinity units
NTU Nephelometric turbidity units

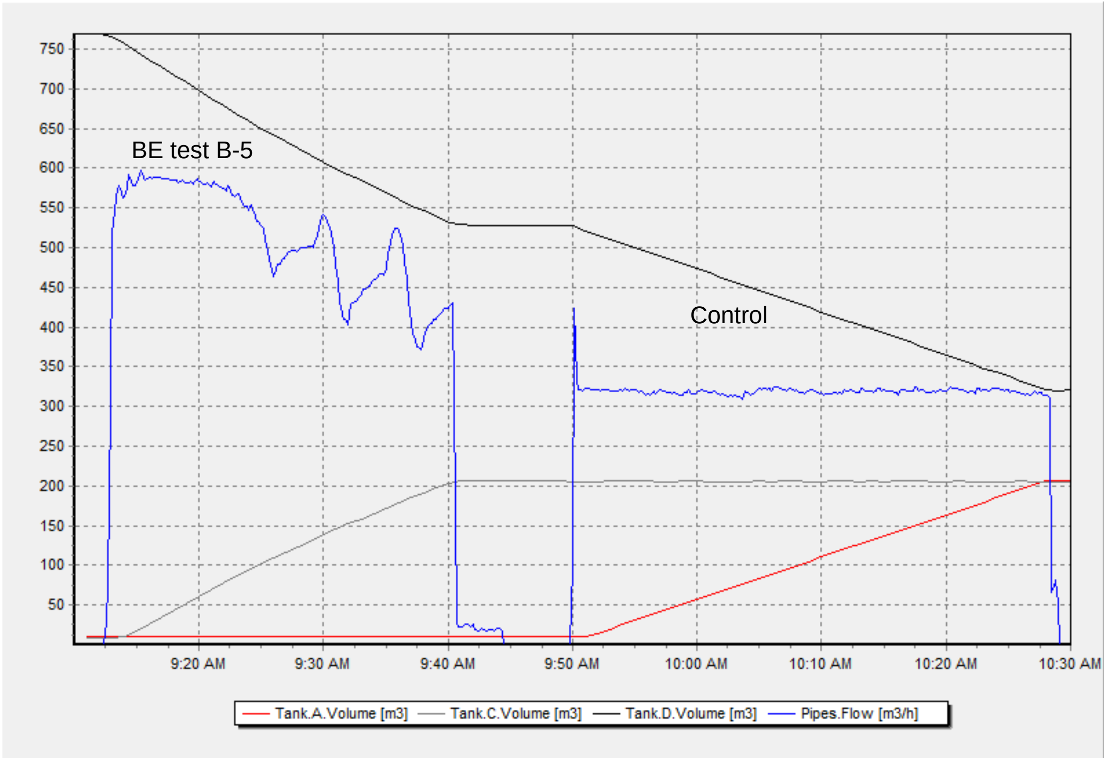


Figure C.5 Biological efficacy test cycles B-5 data plot. Ballast operation

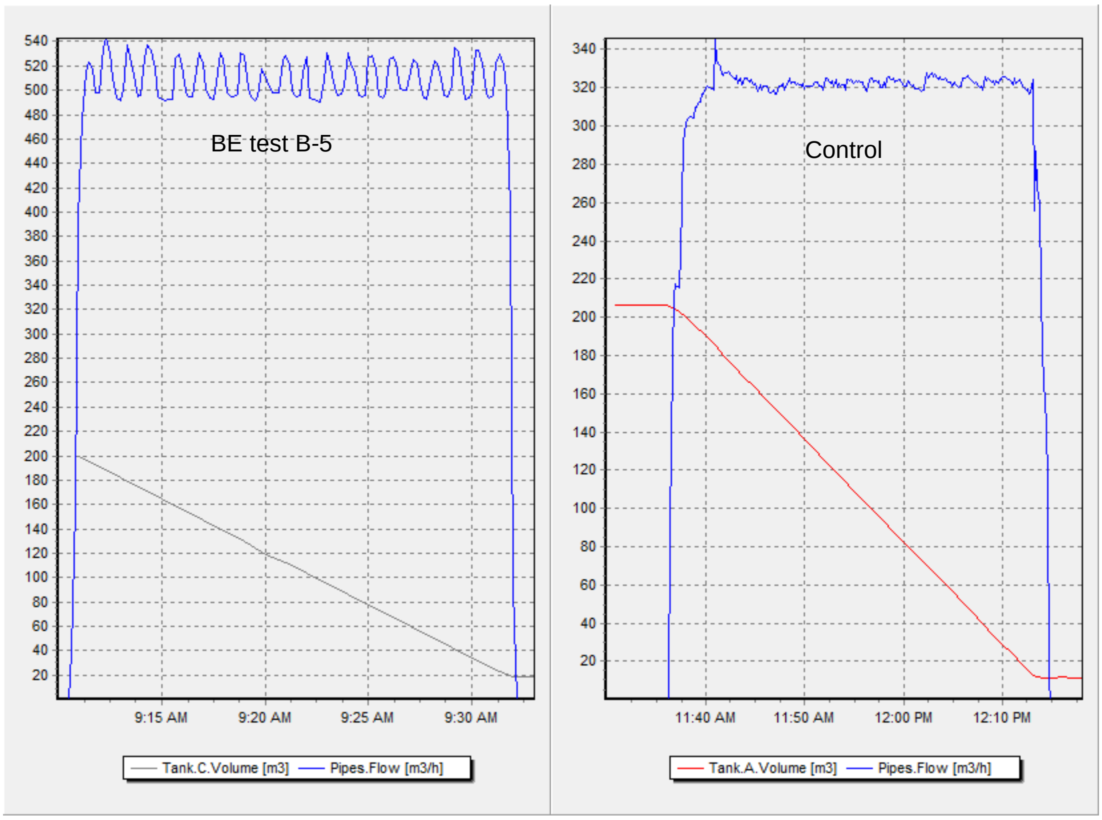


Figure C.6 Biological efficacy test cycles B-5 data plot. De-ballast operation

Table C.11 Biological efficacy test cycle data logging (B-6)

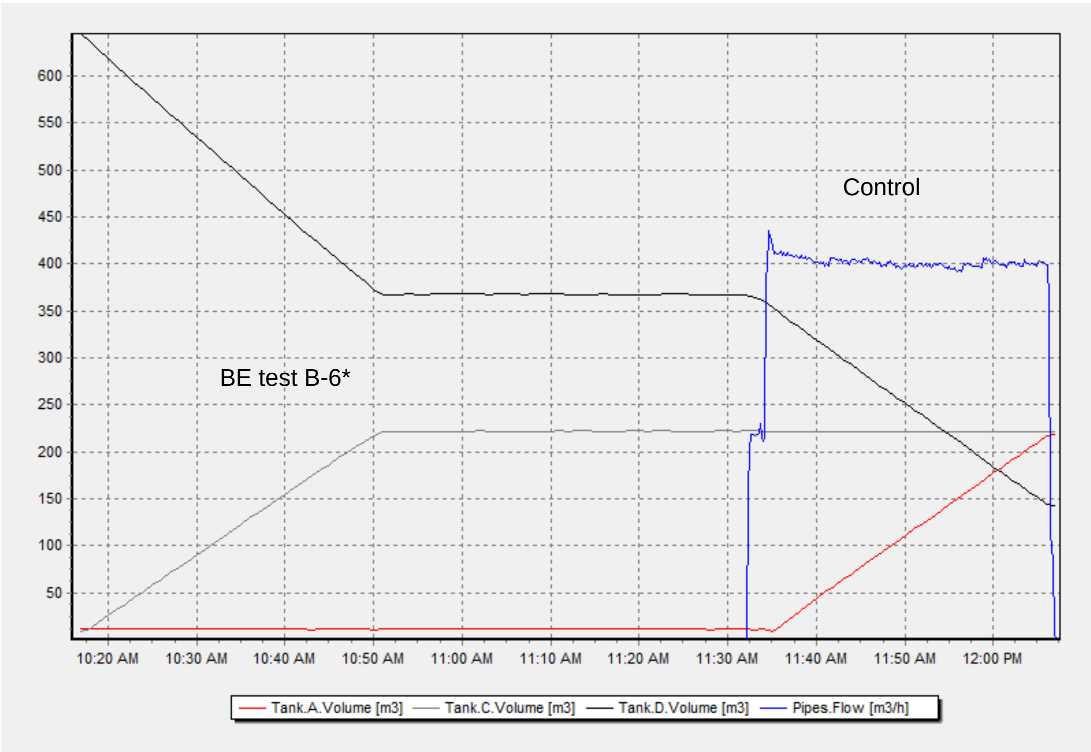
Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Salinity (PSU)	17
Retention tank No.	C1
Test cycle No.	B-6
Use of cultured/harvested organisms	Addition of backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae (*Tetraselmis* sp.)
System cleaned before ballast	Yes
Date and time ballast start	2013.07.11 10:16
Date and time ballast stop	2013.07.11 10:51
Flow rate during ballast (average)	487 m^3/h**
Flow rate to ballast tank (calculated)	397 m^3/h
Power consumption during ballast*	26.65 kWh + 17.87 kWh for cooling power***
UV intensity*	5.7 mW/cm^2
Treated volume during ballast	222 m^3 + 3 m^3
Volume used for ballasting (approx.)	285 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.07.16 13:31
Date and time de-ballast stop	2013.07.16 13:56
Flow rate during discharge (average)	489 m^3/h
Power consumption during de-ballast*	26.55 kWh + 17.87 kWh for cooling power***
UV intensity*	7.5 mW/cm^2
Treated volume during de-ballast	198 m^3
General comments/operational issues	Flow meter check was performed on Trojan flow meter and a difference of approximately 150m^3/h was recorded. Trojan's flow measurement was too high and flow was adjusted manually. Detailed online monitoring data available in enclosed data files.

* Information on manufacturer-specified parameters and power consumption data provided by the client
** Estimated flow rate based on volume decrease in source tank and time
*** *Note from Trojan: Air-cooled version was used for land-based testing primarily due to ease of installation for testing purposes.*

Table C.12 Onsite measurements (B-6) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	96 (±0.21)	8.0 (±0.0071)	17 (±0.00)	18 (±0.021)	40 (±1.3)
TM BWT 500 inlet (T0)	97 (±0.27)	7.9 (±0.0090)	17 (±0.016)	19 (±0.17)	39 (±1.9)
TM BWT 500 1st treatment (T0)	99 (±1.0)	7.9 (±0.028)	17 (±0.042)	19 (±0.045)	40 (±1.4)
TM BWT 500 1st treatment (T5)	48 (±1.1)	7.6 (±0.017)	17 (±0.0021)	19 (±0.36)	8.4 (±0.65)
TM BWT 500 2nd treatment (T5)	50 (±0.69)	7.6 (±0.013)	17 (±0.028)	19 (±0.32)	10 (±1.5)
Control discharge (T5)	36 (±1.6)	7.4 (±0.084)	17 (±0.0049)	20 (±0.39)	0.97 (±0.88)

PSU Practical salinity units
NTU Nephelometric turbidity units



* Flow rate was not recorded due to malfunction of the DHI flow meter

Figure C.7 Biological efficacy test cycles B-6 data plot. Ballast operation

Figure C.8 Biological efficacy test cycles B-6 data plot. De-ballast operation

Table C.13 Biological efficacy test cycle data logging (B-7)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Salinity (PSU)	18
Retention tank No.	C1
Test cycle No.	B-7
Use of cultured/harvested organisms	Addition of backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae (*Tetraselmis* sp.)
System cleaned before ballast	Yes
Date and time ballast start	2013.07.18 10:18
Date and time ballast stop	2013.07.18 10:41
Flow rate during ballast (average)	645 m^3/h
Flow rate to ballast tank (calculated)	558 m^3/h
Power consumption during ballast*	26.63 kWh + 17.67 kWh for cooling power**
UV intensity*	5.6 mW/cm^2
Treated volume during ballast	211 m^3 + 3 m^3
Volume used for ballasting (approx.)	256 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.07.23 10:01
Date and time de-ballast stop	2013.07.23 10:21
Flow rate during discharge (average)	554 m^3/h
Power consumption during de-ballast*	26.58 kWh + 17.67 kWh for cooling power**
UV intensity*	7.4 mW/cm^2
Treated volume during de-ballast	188 m^3
General comments/operational issues	Halfway through the operation, backflush valve was manually closed slightly to decrease backflush and channel more water into the retention tank. Detailed online monitoring data available in enclosed data files.

* Information on manufacturer-specified parameters and power consumption data provided by the client

** *Note from Trojan: Air-cooled version was used for land-based testing primarily due to ease of installation for testing purposes.*

Table C.14 Onsite measurements (B-7) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	97 (±0.32)	8.0 (±0.00)	18 (±0.011)	19 (±0.032)	38 (±0.78)
TM BWT 500 inlet (T0)	98 (±0.55)	8.0 (±0.0035)	18 (±0.00)	19 (±0.021)	39 (±2.5)
TM BWT 500 1st treatment (T0)	99 (±0.45)	7.9 (±0.0095)	18 (±0.037)	19 (±0.015)	38 (±1.1)
TM BWT 500 1st treatment (T5)	67 (±1.5)	7.7 (±0.0070)	18 (±0.0025)	21 (±0.43)	6.2 (±0.45)
TM BWT 500 2nd treatment (T5)	68 (±0.94)	7.7 (±0.0072)	18 (±0.0079)	22 (±0.43)	7.0 (±0.58)
Control discharge (T5)	57 (±1.6)	7.5 (±0.026)	18 (±0.0090)	22 (±0.53)	1.5 (±0.40)

PSU Practical salinity units
NTU Nephelometric turbidity units

Table C.15 Biological efficacy test cycle data logging (B-8)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Salinity (PSU)	18
Retention tank No.	B1
Test cycle No.	B-8
Use of cultured/harvested organisms	Addition of backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae (*Tetraselmis* sp.)
System cleaned before ballast	Yes
Date and time ballast start	2013.07.18 11:43
Date and time ballast stop	2013.07.18 12:06
Flow rate during ballast (average)	624 m^3/h
Flow rate to ballast tank (calculated)	551 m^3/h
Power consumption during ballast*	26.58 kWh + 17.67 kWh for cooling power**
UV intensity*	5.7 mW/cm^2
Treated volume during ballast	208 m^3 + 3 m^3
Volume used for ballasting (approx.)	253 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.07.23 11:40
Date and time de-ballast stop	2013.07.23 12:01
Flow rate during discharge (average)	524 m^3/h
Power consumption during de-ballast*	26.58 kWh + 17.67 kWh for cooling power**
UV intensity*	7.3 mW/cm^2
Treated volume during de-ballast	181 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files

* Information on manufacturer-specified parameters and power consumption data provided by the client

** *Note from Trojan: Air-cooled version was used for land-based testing primarily due to ease of installation for testing purposes.*

Table C.16 Onsite measurements (B-8) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	97 (±0.32)	8.0 (±0.00)	18 (±0.011)	19 (±0.032)	38 (±0.78)
TM BWT 500 inlet (T0)	97 (±0.19)	8.0 (±0.0043)	18 (±0.0039)	19 (±0.024)	40 (±1.3)
TM BWT 500 1st treatment (T0)	99 (±0.23)	7.9 (±0.0047)	18 (±0.063)	19 (±0.020)	38 (±0.49)
TM BWT 500 1st treatment (T5)	62 (±0.71)	7.7 (±0.032)	18 (±0.00)	22 (±0.46)	6.4 (±0.59)
TM BWT 500 2nd treatment (T5)	64 (±0.89)	7.6 (±0.023)	18 (±0.0049)	22 (±0.45)	5.5 (±0.56)
Control discharge (T5)	57 (±1.6)	7.5 (±0.026)	18 (±0.0090)	22 (±0.53)	1.5 (±0.40)

PSU Practical salinity units
NTU Nephelometric turbidity units

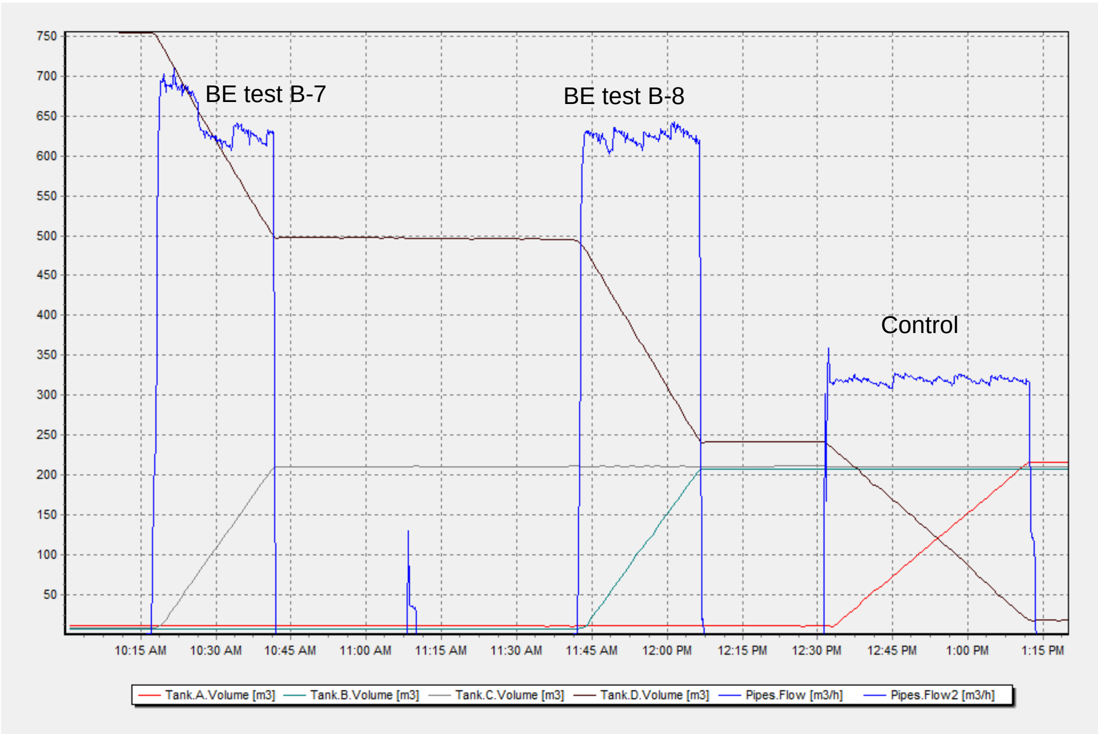


Figure C.9 Biological efficacy test cycle B-7 and B-8 data plot. Ballast operation

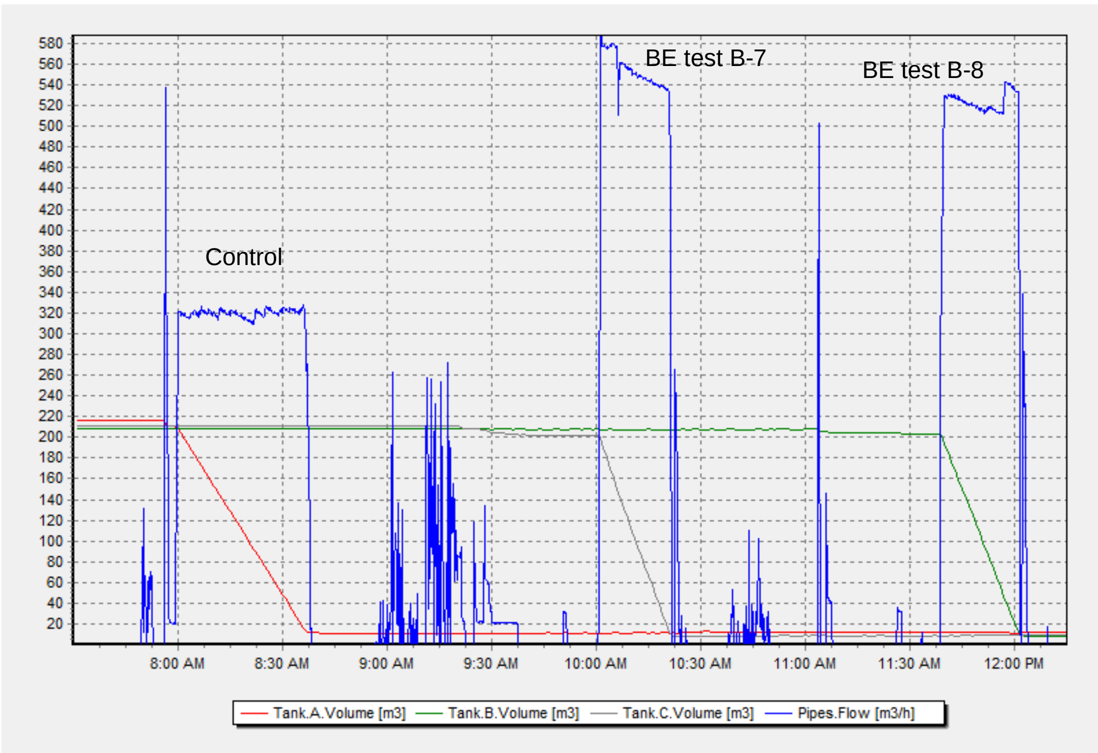


Figure C.10 Biological efficacy test cycle B-7 and B-8 data plot. De-ballast operation

Table C.17 Biological efficacy test cycle data logging (F-1)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom designed filter elements for marine use. 32 µm
Salinity (PSU)	0.37
Retention tank No.	C1
Test cycle No.	F-1
Use of cultured/harvested organisms	No
System cleaned before ballast	Yes
Date and time ballast start	2013.05.02 10:06
Date and time ballast stop	2013.05.02 10:33
Flow rate during ballast (average)	543 m^3/h
Flow rate to ballast tank (calculated)	515 m^3/h
Power consumption during ballast*	26.93 kWh + 17.67 kWh for cooling power**
UV intensity*	2.97 mW/cm^2
Treated volume during ballast	220 m^3 (+ 3 m^3 for sampling)
Volume used for ballasting (approx.)	246 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.05.07 09:42
Date and time de-ballast stop	2013.05.07 10:05
Flow rate during discharge (average)	503 m^3/h
Power consumption during de-ballast*	26.91 kWh + 17.67 kWh for cooling power**
UV intensity*	3.45 mW/cm^2
Treated volume during de-ballast	200 m^3
General comments/operational issues	Ballasting: Lamp warm up stopped due to failure of lamps 33 and 34. Lamps were changed. De-ballast: Start-up was delayed due to a set of lamps that could not be switched on. After repeated attempts, operation was started at 9:42 with no parts replaced.

* Information on manufacturer-specified parameters and power consumption data provided by the client
** *Note from Trojan: Air-cooled version was used for land-based testing primarily due to ease of installation for testing purposes.*

Table C.18 Onsite measurements (F-1) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	105 (±0.27)	8.0 (±0.0047)	0.37 (±0.00)	9.7 (±0.033)	33 (±0.25)
TM BWT 500 inlet (T0)	105 (±0.16)	8.0 (±0.0047)	0.37 (±0.00)	9.7 (±0.0075)	34 (±0.35)
TM BWT 500 1st treatment (T0)	106 (±0.056)	8.1 (±0.0075)	0.36 (±0.00)	9.8 (±0.011)	30 (±0.34)
TM BWT 500 1st treatment (T5)	100 (±0.44)	7.9 (±0.0022)	0.37 (±0.00)	12.2 (±0.30)	16 (±0.62)
TM BWT 500 2nd treatment (T5)	101 (±0.45)	8.0 (±0.0059)	0.37 (±0.00)	12.3 (±0.28)	17 (±1.1)
Control discharge (T5)	93 (±0.84)	7.8 (±0.0045)	0.37 (±0.00)	14.1 (±0.69)	15 (±5.5)

PSU Practical salinity units
NTU Nephelometric turbidity units

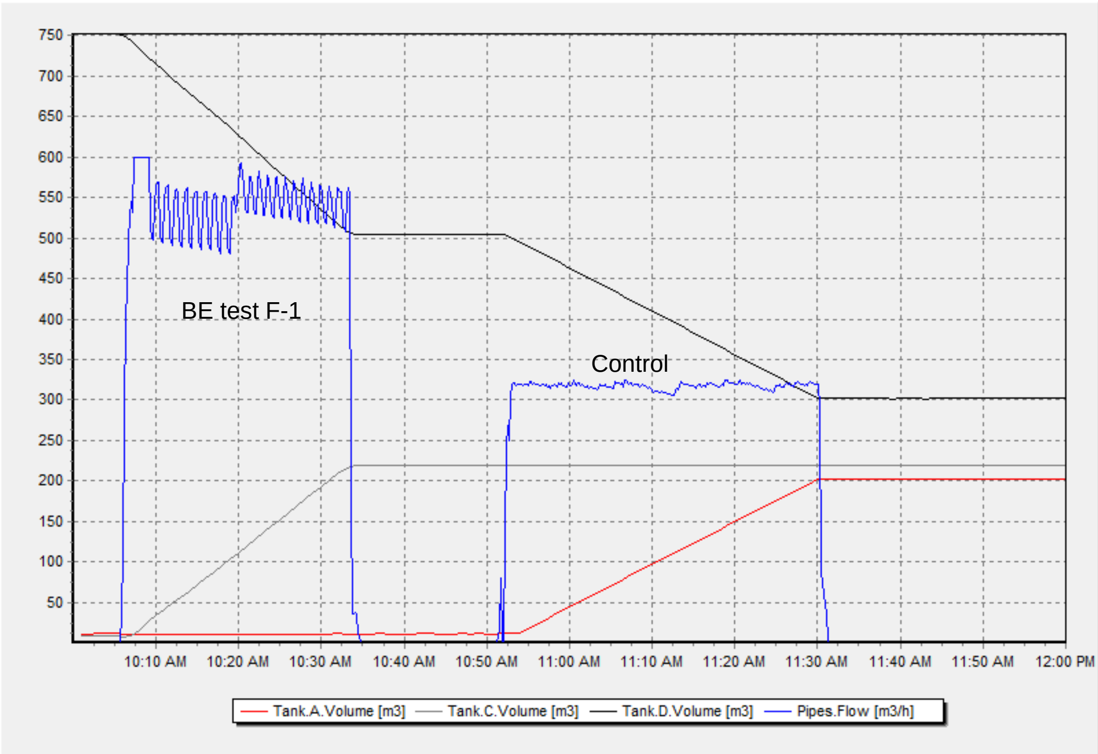


Figure C.11 Biological efficacy test cycle F-1 data plot. Ballast operation

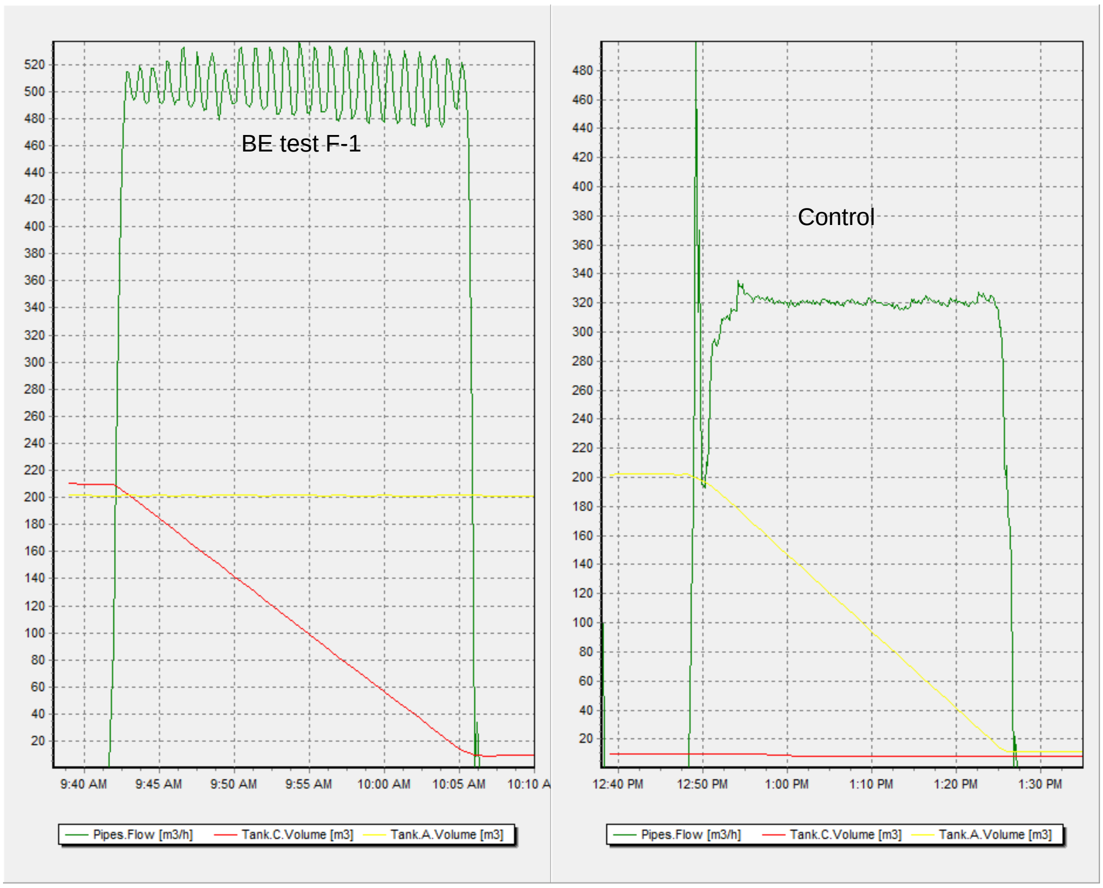


Figure C.12 Biological efficacy test cycles F-1 data plot. De-ballast operation

Table C.19 Biological efficacy test cycle data logging (F-2)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Salinity (PSU)	0.37
Retention tank No.	C1
Test cycle No.	F-2
Use of cultured/harvested organisms	No
System cleaned before ballast	Yes
Date and time ballast start	2013.05.23 10:01
Date and time ballast stop	2013.05.23 10:28
Flow rate during ballast (average)	530 m^3/h
Flow rate to ballast tank (calculated)	502 m^3/h
Power consumption during ballast*	27.07 kWh + 17.67 kWh for cooling power**
UV intensity*	3.1 mW/cm^2
Treated volume during ballast	223 m^3 (+ 3 m^3 for sampling)
Volume used for ballasting (approx.)	237 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.05.28 11:32
Date and time de-ballast stop	2013.05.28 11:55
Flow rate during discharge (average)	507 m^3/h
Power consumption during de-ballast*	26.75 kWh + 17.67 kWh for cooling power**
UV intensity*	3.67 mW/cm^2
Treated volume during de-ballast	191 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files

* Information on manufacturer-specified parameters and power consumption data provided by the client

** *Note from Trojan: Air-cooled version was used for land-based testing primarily due to ease of installation for testing purposes.*

Table C.20 Onsite measurements (F-2) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	93 (±0.45)	8.2 (±0.00048)	0.37 (±0.0041)	14 (±0.13)	30 (±2.1)
TM BWT 500 inlet (T0)	91 (±0.75)	8.2 (±0.00)	0.37 (±0.0026)	13 (±0.039)	31 (±0.75)
TM BWT 500 1st treatment (T0)	92 (±1.1)	8.1 (±0.021)	0.37 (±0.0087)	14 (±0.22)	29 (±0.68)
TM BWT 500 1st treatment (T5)	97 (±0.059)	7.8 (±0.0082)	0.12 (±0.00)	17 (±0.27)	131 (±3.4)
TM BWT 500 2nd treatment (T5)	88 (±0.60)	8.1 (±0.0055)	0.38 (±0.00)	15 (±0.29)	18 (±0.93)
Control discharge (T5)	81 (±0.32)	8.2 (±0.0051)	0.41 (±0.00)	16 (±0.46)	10 (±2.4)

PSU Practical salinity units
NTU Nephelometric turbidity units

Table C.21 Biological efficacy test cycle data logging (F-3)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Salinity (PSU)	0.37
Retention tank No.	B1
Test cycle No.	F-3
Use of cultured/harvested organisms	No
System cleaned before ballast	Yes
Date and time ballast start	2013.05.23 11:42
Date and time ballast stop	2013.05.23 12:08
Flow rate during ballast (average)	523 m^3/h
Flow rate to ballast tank (calculated)	482 m^3/h
Power consumption during ballast*	27.06 kWh + 17.67 kWh for cooling power**
UV intensity*	3.1 mW/cm^2
Treated volume during ballast	206 m^3 + 3 m^3
Volume used for ballasting (approx.)	231 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.05.28 13:37
Date and time de-ballast stop	2013.05.28 13:59
Flow rate during discharge (average)	516 m^3/h
Power consumption during de-ballast*	27.75 kWh + 17.67 kWh for cooling power**
UV intensity*	3.6-3.7 mW/cm^2
Treated volume during de-ballast	183 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files-

* Information on manufacturer-specified parameters and power consumption data provided by the client

** *Note from Trojan: Air-cooled version was used for land-based testing primarily due to ease of installation for testing purposes.*

Table C.22 Onsite measurements (F-3) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	93 (±0.45)	8.2 (±0.00048)	0.37 (±0.0041)	14 (±0.13)	30 (±2.1)
TM BWT 500 inlet (T0)	91 (±0.20)	8.2 (±0.0047)	0.37 (±0.00)	13 (±0.067)	31 (±1.7)
TM BWT 500 1st treatment (T0)	93 (±0.12)	8.1 (±0.014)	0.37 (±0.00)	14 (±0.17)	30 (±0.70)
TM BWT 500 1st treatment (T5)	87 (±0.79)	8.3 (±0.0058)	0.38 (±0.00)	15 (±0.45)	16 (±0.89)
TM BWT 500 2nd treatment (T5)	90 (±2.3)	8.1 (±0.0051)	0.37 (±0.00)	15 (±0.34)	13 (±6.7)
Control discharge (T5)	81 (±0.32)	8.2 (±0.0051)	0.41 (±0.00)	16 (±0.46)	10 (±2.4)

PSU Practical salinity units
NTU Nephelometric turbidity units

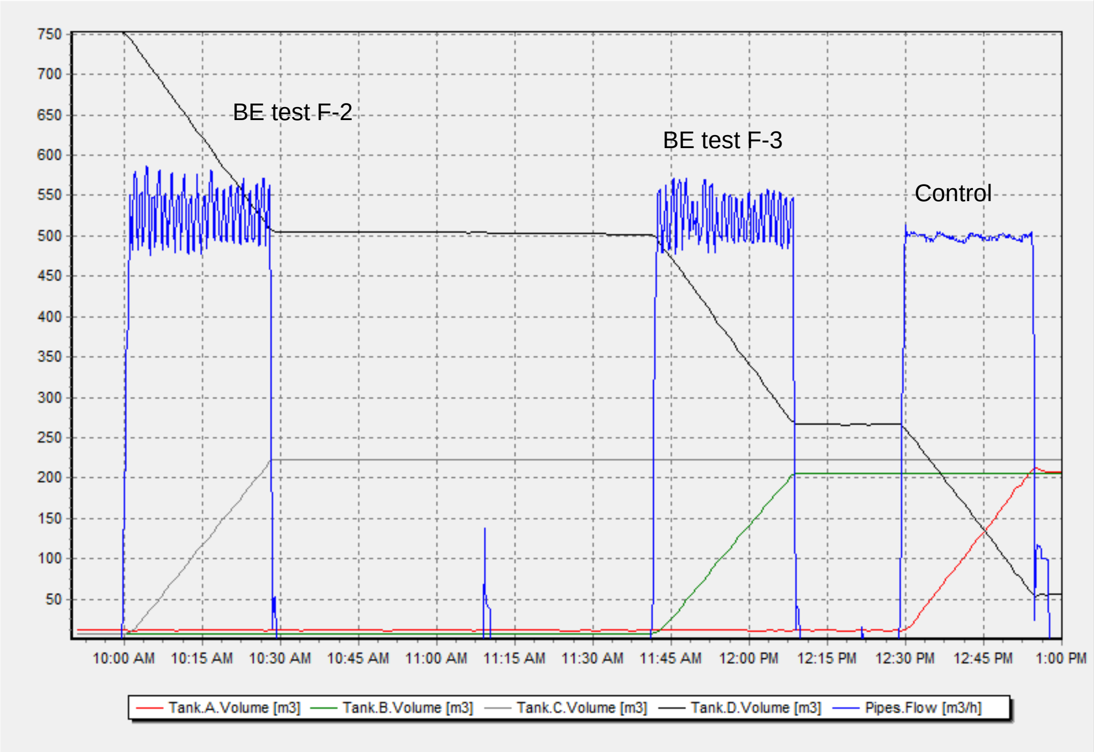


Figure C.13 Biological efficacy test cycles F-2 and F-3 data plot. Ballast operation

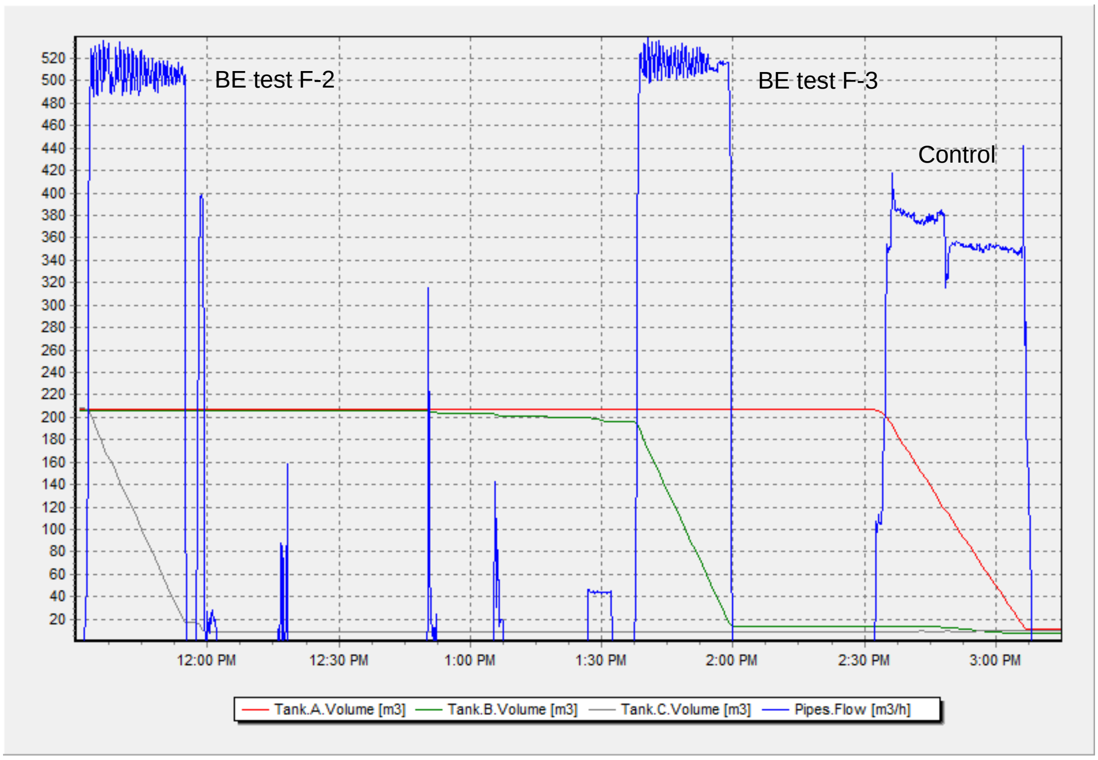


Figure C.14 Biological efficacy test cycles F-2 and F-3 data plot. De-ballast operation

Table C.23 Biological efficacy test cycle data logging (F-4)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Salinity (PSU)	0.41
Retention tank No.	C1
Test cycle No.	F-4
Use of cultured/harvested organisms	No
System cleaned before ballast	Yes
Date and time ballast start	2013.05.30 09:24 and 11:07
Date and time ballast stop	2013.05.30 09:34 and 11:24
Flow rate during ballast (average)	554 m^3/h
Flow rate to ballast tank (calculated)	471 m^3/h
Power consumption during ballast*	26.98 kWh + 17.67 kWh for cooling power**
UV intensity*	2.9 mW/cm^2
Treated volume during ballast	209 m^3 + 3 m^3
Volume used for ballasting (approx.)	291 m^3***
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.06.04 11:10
Date and time de-ballast stop	2013.06.04 11:31
Flow rate during discharge (average)	520 m^3/h
Power consumption during de-ballast*	25.76 kWh + 17.67 kWh for cooling power**
UV intensity*	3.5-3.6 mW/cm^2
Treated volume during de-ballast	176 m^3
General comments/operational issues	Operation stopped at 09:33 as filter motor was not running. This indicated that only one filter candle was being cleaned and the remaining candles were clogged. Filter motor and frequency converter wiring were inspected by Trojan. Operation was restarted at 11:07. Detailed online monitoring data available in enclosed data files.

* Information on manufacturer-specified parameters and power consumption data provided by the client
** *Note from Trojan: Air-cooled version was used for land-based testing primarily due to ease of installation for testing purposes.*
*** Number uncertain due to interruption of the ballasting operation

Table C.24 Onsite measurements (F-4) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	101 (±0.30)	8.3 (±0.0089)	0.41 (±0.00)	15 (±0.037)	37 (±0.80)
TM BWT 500 inlet (T0)	100 (±0.41)	8.2 (±0.0049)	0.41 (±0.00)	15 (±0.047)	39 (±1.4)
TM BWT 500 1st treatment (T0)	102 (±1.3)	8.1 (±0.0054)	0.41 (±0.00)	15 (±0.061)	36 (±1.8)
TM BWT 500 1st treatment (T5)	90 (±1.7)	8.4 (±0.0019)	0.42 (±0.00)	17 (±0.31)	21 (±2.7)
TM BWT 500 2nd treatment (T5)	92 (±1.8)	8.1 (±0.0044)	0.42 (±0.00)	17 (±0.31)	19 (±1.5)
Control discharge (T5)	85 (±0.38)	8.2 (±0.0071)	0.41 (±0.0017)	17 (±0.50)	9.1 (±2.5)

PSU Practical salinity units
NTU Nephelometric turbidity units

Table C.25 Biological efficacy test cycle data logging (F-5)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client-specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Salinity (PSU)	0.41
Retention tank No.	B1
Test cycle No.	F-5
Use of cultured/harvested organisms	No
System cleaned before ballast	Yes
Date and time ballast start	2013.05.30 12:12
Date and time ballast stop	2013.05.30 12:37
Flow rate during ballast (average)	564 m^3/h
Flow rate to ballast tank (calculated)	490 m^3/h
Power consumption during ballast*	27.23 kWh + 17.67 kWh for cooling power**
UV intensity*	3.0 mW/cm^2
Treated volume during ballast	201 m^3 + 3 m^3
Volume used for ballasting (approx.)	238 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.06.04 12:42
Date and time de-ballast stop	2013.06.04 13:03
Flow rate during discharge (average)	519 m^3/h
Power consumption during de-ballast*	25.78 kWh + 17.67 kWh for cooling power**
UV intensity*	3.6 mW/cm^2
Treated volume during de-ballast	171 m^3
General comments/operational issues	Detailed online monitoring data available in enclosed data files. Almost constantly backflush at approx. 95 m^3/h. Filter top cap removed to inspect backwash mechanism. Filter rods controlled.

* Information on manufacturer-specified parameters and power consumption data provided by the client

** *Note from Trojan: Air-cooled version was used for land-based testing primarily due to ease of installation for testing purposes.*

Table C.26 Onsite measurements (F-5) (standard deviations in parentheses)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Control inlet (T0)	101 (±0.30)	8.3 (±0.0089)	0.41 (±0.00)	15 (±0.037)	37 (±0.80)
TM BWT 500 inlet (T0)	101 (±0.14)	8.2 (±0.0048)	0.41 (±0.00)	15 (±0.033)	38 (±0.40)
TM BWT 500 1st treatment (T0)	103 (±0.55)	8.1 (±0.0027)	0.41 (±0.00)	15 (±0.60)	36 (±2.8)
TM BWT 500 1st treatment (T5)	91 (±1.9)	8.2 (±0.0048)	0.41 (±0.00)	17 (±0.39)	20 (±1.7)
TM BWT 500 2nd treatment (T5)	95 (±4.6)	8.0 (±0.0023)	0.41 (±0.00)	17 (±0.38)	20 (±2.5)
Control discharge (T5)	85 (±0.38)	8.2 (±0.0071)	0.41 (±0.0017)	17 (±0.50)	9.1 (±2.5)

PSU Practical salinity units
NTU Nephelometric turbidity units

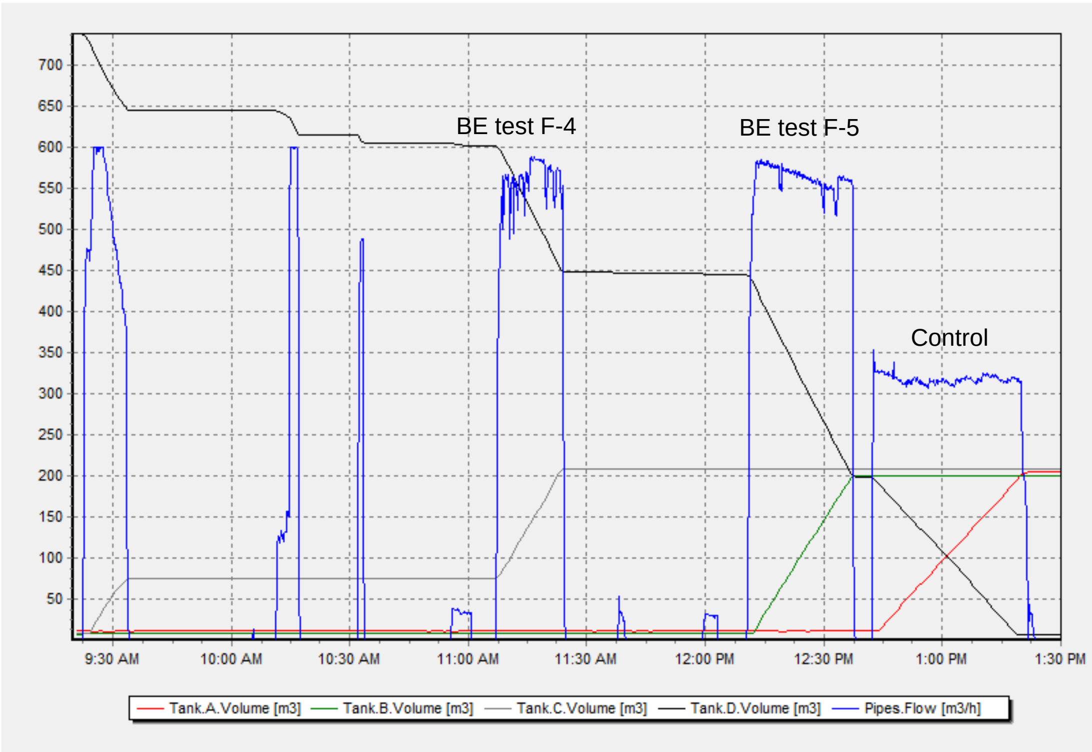


Figure C.15 Biological efficacy test cycles F-4 and F-5 data plot. Ballast operation

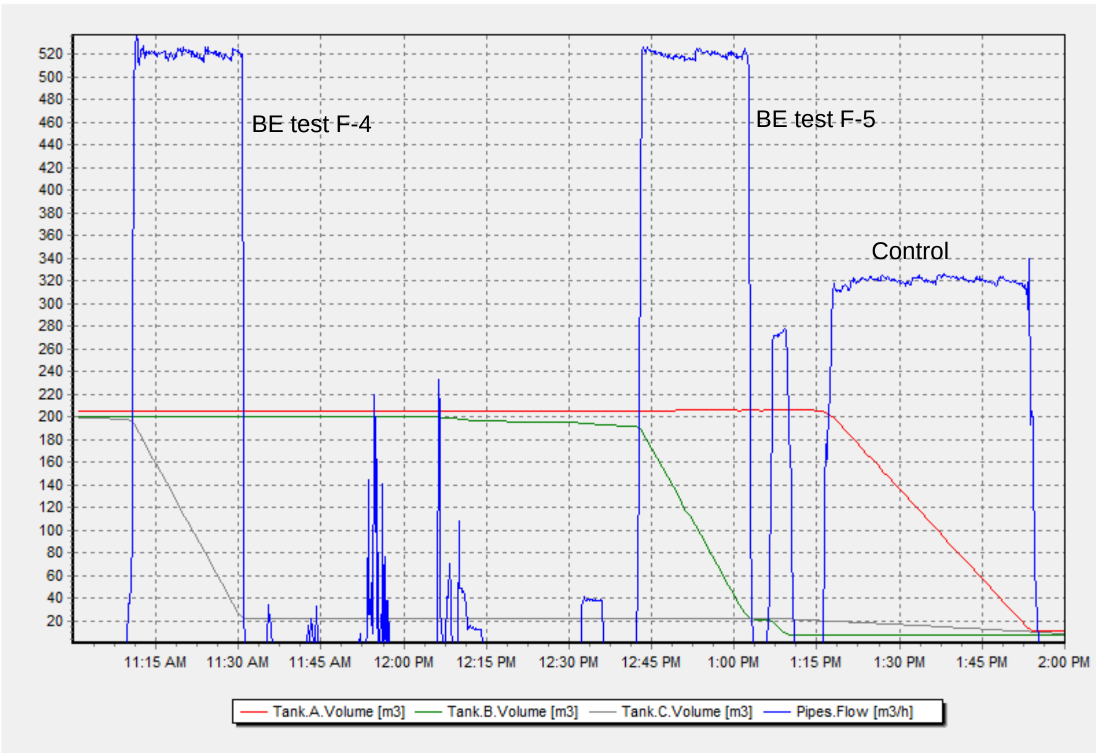


Figure C.16 Biological efficacy test cycles F-4 and F-5 data plot. De-ballast operation

APPENDIX D

Data logging from the operation and maintenance (O&M) testing with Trojan Marinex^{TM} BWT 500

Table D.1 Operation and maintenance test cycle data logging (O&M-1)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Test cycle No.	O&M-1
Date and time start	2013.05.27 10:15
Date and time stop	2013.05.27 14:30
Flow rate (average)	480 m^3/h
Power consumption*	25.57 kWh
UV intensity*	8.2 mW/cm^2
Treated volume	2,043 m^3
General comments/operational issues	The O&M test was conducted in ballast mode with filtration and UV treatment. The O&M test was conducted by sea-to-sea operation with ambient water conditions. The flow rate and accumulated volume were measured by a flow meter installed in the piping before the BWMS. Detailed online monitoring data available in data files on enclosed CD-ROM.

* Information on manufacturer specified parameters and power consumption data provided by the client.

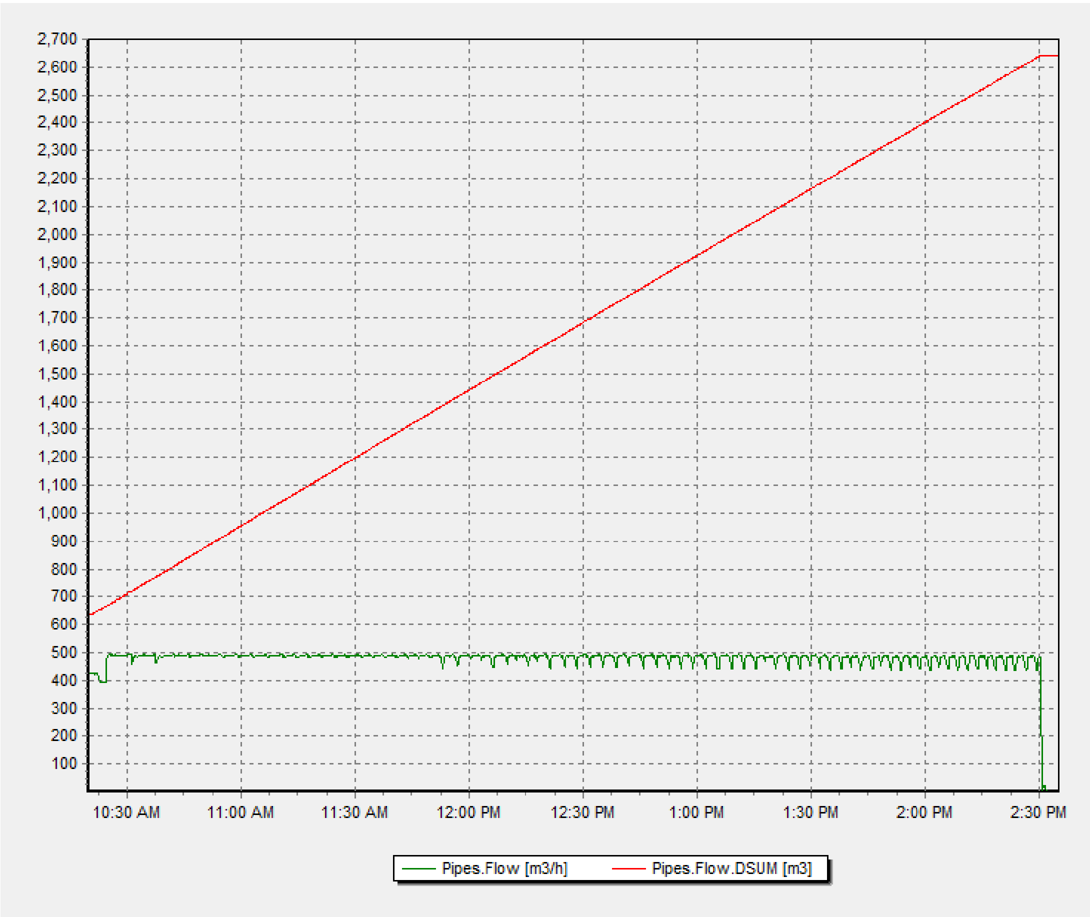


Figure D.1 Operation and maintenance test cycle O&M-1 data plot

Table D.2 Operation and maintenance test cycle data logging (O&M-2)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Test cycle No.	O&M-2
Date and time start	2013.06.19 10:50
Date and time stop	2013.06.19 16:15
Flow rate (average)	371 m^3/h
Power consumption*	26.76 kWh
UV intensity*	7.9 mW/cm^2
Treated volume	2,018 m^3
General comments/operational issues	The O&M test was conducted in ballast mode with filtration and UV treatment. The O&M test was conducted by sea-to-sea operation with ambient water conditions. The flow rate and accumulated volume were measured by a flow meter installed in the piping before the BWMS. Detailed online monitoring data available in data files on enclosed CD-ROM.

* Information on manufacturer specified parameters and power consumption data provided by the client.

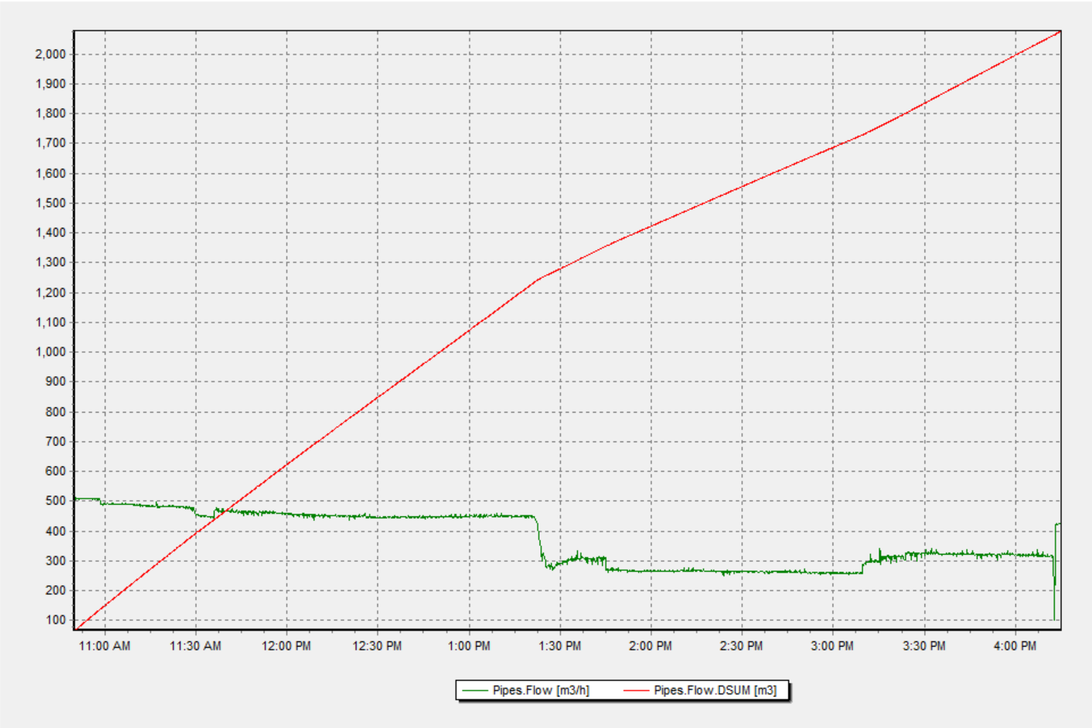


Figure D.2 Operation and maintenance test cycle O&M-2 data plot

Table D.3 Operation and maintenance test cycle data logging (O&M-3)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom designed filter elements for marine use. 32 µm
Test cycle No.	O&M 3
Date and time start	2013.06.24 11:55
Date and time stop	2013.06.24 15:59
Flow rate (average)	497 m^3/h
Power consumption*	26.72 kWh
UV intensity*	7.6 mW/cm^2
Treated volume	2,023 m^3
General comments/operational issues	The O&M test was conducted in ballast mode with filtration and UV treatment. The O&M test was conducted by sea-to-sea operation with ambient water conditions. The flow rate and accumulated volume were measured by a flow meter installed in the piping before the BWMS. Detailed online monitoring data available in data files on enclosed CD-ROM.

* Information on manufacturer specified parameters and power consumption data provided by the client.

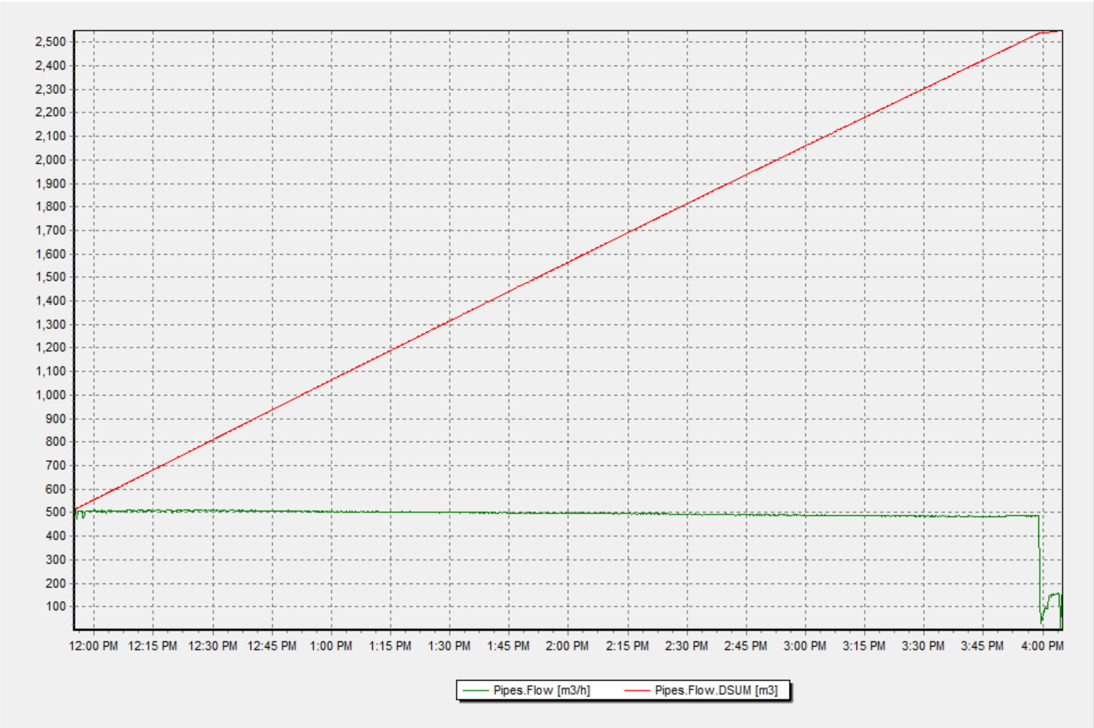


Figure D.3 Operation and maintenance test cycle O&M-3 data plot

Table D.4 Operation and maintenance test cycle data logging (O&M-4)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Test cycle No.	O&M-4
Date and time start	2013.06.26 09:10
Date and time stop	2013.06.26 13:22
Flow rate (average)	458 m^3/h
Power consumption*	26.74 kWh
UV intensity*	8.2 mW/cm^2
Treated volume	1,923 m^3
General comments/operational issues	The O&M test was conducted in ballast mode with filtration and UV treatment. The O&M test was conducted by sea-to-sea operation with ambient water conditions. The flow rate and accumulated volume were measured by a flow meter installed in the piping before the BWMS. Detailed online monitoring data available in data files on enclosed CD-ROM.

* Information on manufacturer specified parameters and power consumption data provided by the client.

Figure D.4 Operation and maintenance test cycle O&M-4 data plot

Table D.5 Operation and maintenance test cycle data logging (O&M-5)

Subject	Results
Client treatment system	Trojan Marinex™ BWT 500
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	1 UV unit: Forty-eight (48) low pressure high efficiency UV lamps (500 Watts each) 1 filter unit: Twenty-four (24) super duplex custom-designed filter elements for marine use. 32 µm
Test cycle No.	O&M-5
Date and time start	2013.07.01 11:39
Date and time stop	2013.07.01 15:48
Flow rate (average)	504 m^3/h
Power consumption*	26.69 kWh
UV intensity*	8.3 mW/cm^2
Treated volume	2,099 m^3
General comments / operational issues	The O&M test was conducted in ballast mode with filtration and UV treatment. The O&M test was conducted by sea-to-sea operation with ambient water conditions. The flow rate and accumulated volume were measured by a flow meter installed in the piping before the BWMS. Detailed online monitoring data available in data files on enclosed CD-ROM.

* Information on manufacturer specified parameters and power consumption data provided by the client.

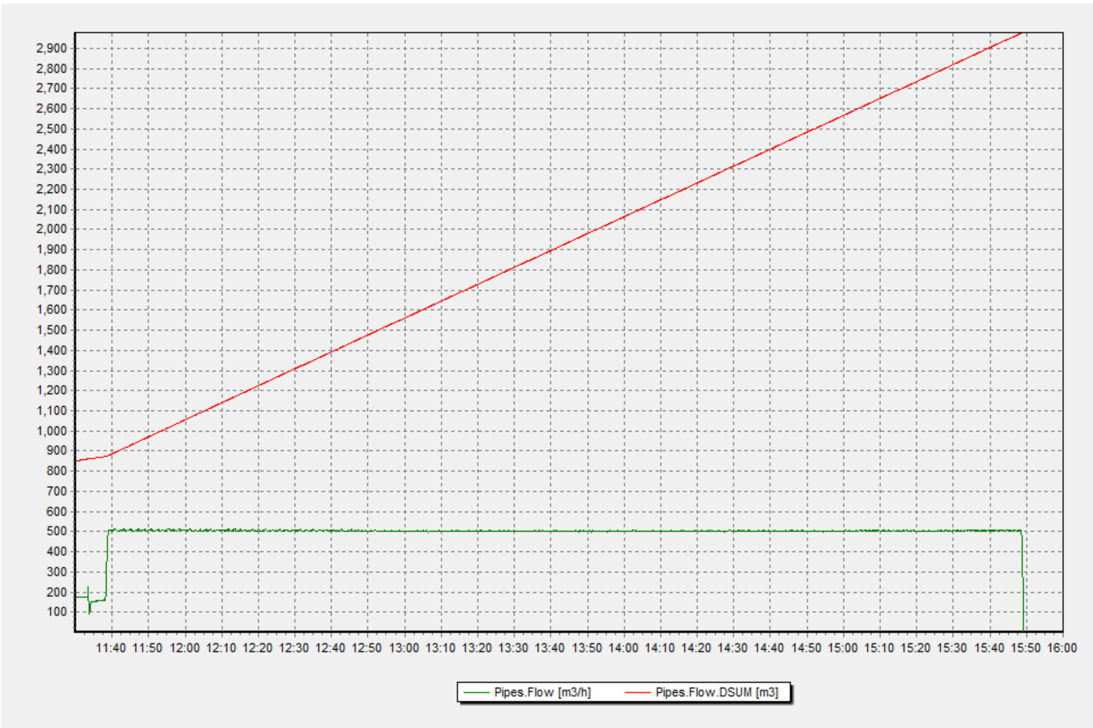


Figure D.5 Operation and maintenance test cycle O&M-5 data plot

APPENDIX E

Detailed data on physical-chemical parameters and biological efficacy analyses in land-based testing with Trojan Marinex^{TM} BWT 500

Physical-chemical parameters

Table E.1 Measurements of total suspended solids (TSS)

Test cycle	Water type	TSS (mg/L)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	60	57	62	**60**	±2.6
	Treated T0	58	56	56	**57**	±1.3
	Treated discharge	14	11	12	**12**	±1.5
	Control discharge	6.1	5.6	5.0	**5.6**	±0.57
B-2	Inlet	60	57	62	**60**	±2.6
	Treated T0	58	57	54	**56**	±2.1
	Treated discharge	13	10	11	**11**	±1.1
	Control discharge	6.1	5.6	5.0	**5.6**	±0.57
B-3	Inlet	59	56	57	**57**	±1.5
	Treated T0	50	49	48	**49**	±1.3
	Treated discharge	12	11	11	**11**	±0.75
	Control discharge	1.1	7.0	6.3	**4.8**	±3.2
B-4	Inlet	59	56	57	**57**	±1.5
	Treated T0	46	46	46	**46**	±0.20
	Treated discharge	13	12	12	**12**	±0.69
	Control discharge	1.1	7.0	6.3	**4.8**	±3.2
B-5	Inlet	60	60	63	**61**	±1.5
	Treated T0	53	53	51	**52**	±1.1
	Treated discharge	6.6	6.2	6.1	**6.3**	±0.30
	Control discharge	2.6	2.2	2.4	**2.4**	±0.23
B-6	Inlet	72	77	74	**74**	±2.8
	Treated T0	57	56	54	**56**	±1.5
	Treated discharge	10	8.7	8.1	**9.0**	±1.2
	Control discharge	1.7	2.1	2.2	**2.0**	±0.26
B-7	Inlet	61	60	62	**61**	±1.1
	Treated T0	54	56	56	**55**	±1.0
	Treated discharge	6.2	5.5	4.9	**5.5**	±0.66
	Control discharge	2.1	1.6	2.7	**2.1**	±0.55
B-8	Inlet	61	60	62	**61**	±1.1
	Treated T0	55	55	54	**55**	±0.43
	Treated discharge	6.9	6.4	4.9	**6.0**	±1.1
	Control discharge	2.1	1.6	2.7	**2.1**	±0.55
F-1	Inlet	59	60	63	**61**	±1.8
	Treated T0	59	52	55	**55**	±3.7
	Treated discharge	23	17	20	**20**	±2.9
	Control discharge	14	13	15	**14**	±1.0
F-2	Inlet	55	54	58	**56**	±2.3
	Treated T0	51	50	51	**51**	±0.77
	Treated discharge	21	22	15	**19**	±3.5
	Control discharge	13	9.2	9.5	**11**	±2.3

Test cycle	Water type	TSS (mg/L)				
		FR1	FR2	FR3	AVG	STD
F-3	Inlet	55	54	58	**56**	±2.3
	Treated T0	55	51	51	**52**	±2.3
	Treated discharge	21	21	20	**21**	±0.71
	Control discharge	13	9.2	9.5	**11**	±2.3
F-4	Inlet	60	60	61	**61**	±0.77
	Treated T0	55	53	56	**55**	±1.7
	Treated discharge	22	21	22	**22**	±0.64
	Control discharge	11	6.0	6.5	**7.8**	±2.7
F-5	Inlet	60	60	61	**61**	±0.77
	Treated T0	58	55	54	**55**	±1.9
	Treated discharge	21	20	20	**20**	±0.67
	Control discharge	11	6.0	6.5	**7.8**	±2.7

FR Field replicate
AVG Average
STD Standard deviation

Table E.2 Measurements of particulate organic carbon (POC)

Test cycle	Water type	POC (mg/L)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	7.4	4.2	5.0	**5.5**	±1.6
	Treated discharge	7.2	7.2	8.9	**7.7**	±0.96
	Control discharge	0.59	0.29	1.0	**0.64**	±0.38
B-2	Inlet	7.4	4.2	5.0	**5.5**	±1.6
	Treated discharge	1.0	1.4	1.5	**1.3**	±0.23
	Control discharge	0.59	0.29	1.0	**0.64**	±0.38
B-3	Inlet	7.5	7.7	7.7	**7.6**	±0.13
	Treated discharge	<0.10	<0.10	<0.10	**<0.10**	-
	Control discharge	<0.10	<0.10	0.22	**0.14**	±0.068
B-4	Inlet	7.5	7.7	7.7	**7.6**	±0.13
	Treated discharge	0.10	<0.10	<0.10	**0.10**	±0.00035
	Control discharge	<0.10	<0.10	0.22	**0.14**	±0.068
B-5	Inlet	5.7	5.8	5.3	**5.6**	±0.28
	Treated discharge	0.58	0.65	0.10	**0.45**	±0.30
	Control discharge	1.0	0.84	1.2	**1.0**	±0.19
B-6	Inlet	6.2	6.7	7.4	**6.8**	±0.63
	Treated discharge	0.47	0.38	1.1	**0.65**	±0.39
	Control discharge	0.46	1.2	1.3	**0.98**	±0.46
B-7	Inlet	5.4	6.7	4.5	**5.5**	±1.1
	Treated discharge	1.5	2.4	2.5	**2.1**	±0.57
	Control discharge	0.59	0.95	1.4	**0.99**	±0.42
B-8	Inlet	5.4	6.7	4.5	**5.5**	±1.1
	Treated discharge	1.8	0.61	0.66	**1.0**	±0.70
	Control discharge	0.59	0.95	1.4	**0.99**	±0.42
F-1	Inlet	5.2	5.5	6.5	**5.7**	±0.72
	Treated discharge	2.6	2.5	2.2	**2.4**	±0.20
	Control discharge	0.82	0.56	0.49	**0.62**	±0.17
F-2	Inlet	6.7	6.4	5.6	**6.2**	±0.55
	Treated discharge	0.87	0.37	<0.10	**0.39**	±0.44
	Control discharge	0.58	0.94	1.3	**0.94**	±0.36
F-3	Inlet	6.7	6.4	5.6	**6.2**	±0.55
	Treated discharge	1.4	0.35	0.76	**0.85**	±0.54
	Control discharge	0.58	0.94	1.3	**0.94**	±0.36
F-4	Inlet	6.8	6.2	5.0	**6.0**	±0.91
	Treated discharge	1.3	1.4	0.32	**1.0**	±0.62
	Control discharge	0.40	0.64	<0.10	**0.38**	±0.27
F-5	Inlet	6.8	6.2	5.0	**6.0**	±0.91
	Treated discharge	0.80	1.1	0.85	**0.91**	±0.14
	Control discharge	0.40	0.64	<0.10	**0.38**	±0.27

FR Field replicate
AVG Average
STD Standard deviation

Table E.3 Measurements of dissolved organic carbon (DOC)

Test cycle	Water type	DOC (mg/L)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	5.5	6.7	5.9	**6.0**	±0.56
	Treated discharge	4.0	4.1	4.1	**4.1**	±0.054
	Control discharge	3.9	4.1	3.5	**3.8**	±0.33
B-2	Inlet	5.5	6.7	5.9	**6.0**	±0.56
	Treated discharge	3.9	3.5	3.7	**3.7**	±0.19
	Control discharge	3.9	4.1	3.5	**3.8**	±0.33
B-3	Inlet	6.7	6.6	6.8	**6.7**	±0.08
	Treated discharge	3.6	3.4	3.3	**3.4**	±0.15
	Control discharge	4.1	3.3	3.3	**3.5**	±0.45
B-4	Inlet	6.7	6.6	6.8	**6.7**	±0.082
	Treated discharge	3.6	3.5	3.6	**3.5**	±0.061
	Control discharge	4.1	3.3	3.3	**3.5**	±0.45
B-5	Inlet	6.6	6.9	7.0	**6.8**	±0.17
	Treated discharge	2.9	3.0	3.0	**2.9**	±0.051
	Control discharge	2.8	2.6	2.6	**2.6**	±0.094
B-6	Inlet	7.0	6.8	6.8	**6.9**	±0.12
	Treated discharge	4.9	5.1	5.2	**5.1**	±0.14
	Control discharge	6.3	4.9	5.8	**5.7**	±0.73
B-7	Inlet	8.5	8.2	8.1	**8.3**	±0.24
	Treated discharge	7.1	6.9	6.6	**6.9**	±0.22
	Control discharge	7.3	6.9	7.0	**7.0**	±0.23
B-8	Inlet	8.5	8.2	8.1	**8.3**	±0.24
	Treated discharge	7.3	5.7	6.0	**6.3**	±0.86
	Control discharge	7.3	6.9	7.0	**7.0**	±0.23
F-1	Inlet	8.4	8.0	8.1	**8.2**	±0.20
	Treated discharge	8.0	8.3	8.7	**8.3**	±0.33
	Control discharge	9.5	9.4	9.9	**9.6**	±0.23
F-2	Inlet	7.8	8.3	7.8	**8.0**	±0.26
	Treated discharge	5.0	5.2	5.4	**5.2**	±0.20
	Control discharge	5.3	5.0	5.2	**5.2**	±0.13
F-3	Inlet	7.8	8.3	7.8	**8.0**	±0.26
	Treated discharge	5.1	5.5	5.1	**5.3**	±0.22
	Control discharge	5.3	5.0	5.2	**5.2**	±0.13
F-4	Inlet	8.1	8.1	8.3	**8.2**	±0.11
	Treated discharge	7.6	7.5	7.8	**7.6**	±0.18
	Control discharge	8.7	5.9	8.9	**7.8**	±1.7
F-5	Inlet	8.1	8.1	8.3	**8.2**	±0.11
	Treated discharge	7.5	7.7	7.9	**7.7**	±0.18
	Control discharge	8.7	5.9	8.9	**7.8**	±1.7

FR Field replicate
AVG Average
STD Standard deviation

Table E.4 Concentration of mineral materials (MM). Concentration determined as the difference between the total suspended solids (TSS) and the particulate organic carbon (POC).

Test cycle	Water type	MM (mg/L)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	52	53	57	**54**	±2.7
	Treated discharge	6.4	3.5	3.1	**4.3**	±1.8
	Control discharge	5.5	5.3	4.0	**4.9**	±0.8
B-2	Inlet	52	53	57	**54**	±2.7
	Treated discharge	12	10	10	**11**	±1.1
	Control discharge	5.5	5.3	4.0	**4.9**	±0.8
B-3	Inlet	51	48	50	**50**	±1.6
	Treated discharge	12	11	11	**11**	±0.74
	Control discharge	1.0	6.9	6.1	**4.7**	±3.2
B-4	Inlet	51	48	50	**50**	±1.6
	Treated discharge	13	12	11	**12**	±0.69
	Control discharge	1.0	6.9	6.1	**4.7**	±3.2
B-5	Inlet	54	55	57	**55**	±1.7
	Treated discharge	6.0	5.5	6.0	**5.8**	±0.29
	Control discharge	1.6	1.3	1.2	**1.4**	±0.18
B-6	Inlet	65	70	66	**67**	±2.7
	Treated discharge	9.9	8.3	7.0	**8.4**	±1.4
	Control discharge	1.3	0.90	0.94	**1.0**	±0.21
B-7	Inlet	55	53	57	**55**	±2.2
	Treated discharge	4.7	3.1	2.3	**3.4**	±1.2
	Control discharge	1.5	0.66	1.3	**1.1**	±0.43
B-8	Inlet	55	53	57	**55**	±2.2
	Treated discharge	5.0	5.8	4.2	**5.0**	±0.79
	Control discharge	1.5	0.66	1.3	**1.1**	±0.43
F-1	Inlet	54	55	56	**55**	±1.1
	Treated discharge	20	15	17	**17**	±2.8
	Control discharge	13	12	14	**13**	±1.1
F-2	Inlet	48	47	53	**49**	±2.9
	Treated discharge	20	22	15	**19**	±3.3
	Control discharge	13	8.2	8.2	**9.8**	±2.7
F-3	Inlet	48	47	53	**49**	±2.9
	Treated discharge	20	21	19	**20**	±0.74
	Control discharge	13	8.2	8.2	**9.8**	±2.7
F-4	Inlet	54	54	57	**55**	±1.6
	Treated discharge	21	20	22	**21**	±1.1
	Control discharge	11	5.4	6.5	**7.5**	±2.7
F-5	Inlet	54	54	57	**55**	±1.6
	Treated discharge	20	19	19	**19**	±0.70
	Control discharge	11	5.4	6.5	**7.5**	±2.7

FR Field replicate
AVG Average
STD Standard deviation

Table E.5 Measurements of UV transmittance (UV-T)

Test cycle	Water type	UV-T (%)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	59	58	60	**59**	±1.1
	Inlet; 0.2-µm filter	88	88	87	**88**	±0.66
B-2	Inlet	59	58	60	**59**	±1.1
	Inlet; 0.2-µm filter	88	88	87	**88**	±0.66
B-3	Inlet	67	69	72	**69**	±2.3
	Inlet; 0.2-µm filter	87	87	86	**87**	±0.12
B-4	Inlet	67	69	72	**69**	±2.3
	Inlet; 0.2-µm filter	87	87	86	**87**	±0.12
B-5	Inlet	59	63	61	**61**	±1.9
	Inlet; 0.2-µm filter	88	88	88	**88**	±0.10
B-6	Inlet	59	58	61	**59**	±1.4
	Inlet; 0.2-µm filter	89	89	88	**88**	±0.17
B-7	Inlet	59	58	61	**59**	±1.1
	Inlet; 0.2-µm filter	87	87	87	**87**	±0.20
B-8	Inlet	59	58	61	**59**	±1.1
	Inlet; 0.2-µm filter	87	87	87	**87**	±0.20
F-1	Inlet	47	48	48	**48**	±0.55
	Inlet; 0.2-µm filter	71	71	71	**71**	±0.07
F-2	Inlet	48	48	49	**48**	±0.52
	Inlet; 0.2-µm filter	72	72	72	**72**	±0.15
F-3	Inlet	48	48	49	**48**	±0.52
	Inlet; 0.2-µm filter	72	72	72	**72**	±0.15
F-4	Inlet	46	45	46	**46**	±0.44
	Inlet; 0.2-µm filter	73	73	73	**73**	±0.21
F-5	Inlet	46	45	46	**46**	±0.44
	Inlet; 0.2-µm filter	73	73	73	**73**	±0.21

FR Field replicate
AVG Average
STD Standard deviation

Organism size class ≥50 µm

Table E.6 Enumeration of organisms ≥50 µm. Inlet sample volume: 20 L per field replicate. Treated sample volume: 1,000 L per field replicate.

Test cycle	Water type	Organisms ≥50 µm (organisms/m^3)										
		FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	AVG	STD
B-1	Inlet	774,783	720,417	773,667	712,217	894,400	804,600	699,400	762,700	710,650	**761,426**	±61,649
	Treated T0	1,550	1,456	1,373	-	-	-	-	-	-	**1,460**	±88
	Treated discharge*	4.0	4.0	4.0	-	-	-	-	-	-	**4.0**	±0.0
	Control discharge	76,562	155,969	128,560	-	-	-	-	-	-	**120,364**	±40,333
B-2	Inlet	774,783	720,417	773,667	712,217	894,400	804,600	699,400	762,700	710,650	**761,426**	±61,649
	Treated T0	1,044	1,462	693	-	-	-	-	-	-	**1,066**	±385
	Treated discharge*	2,0	2,0	4,0	-	-	-	-	-	-	**2.7**	±1.2
	Control discharge	76,562	155,969	128,560	-	-	-	-	-	-	**120,364**	±40,333
B-3	Inlet	415,950	238,667	346,667	304,000	285,250	348,300	321,667	322,400	377,000	**328,878**	±51,654
	Treated T0	114	135	131	-	-	-	-	-	-	**127**	±11
	Treated discharge*	6.0	4.0	5.0	-	-	-	-	-	-	**5.0**	±1.0
	Control discharge	55,610	68,951	65,375	-	-	-	-	-	-	**63,312**	±6,906
B-4	Inlet	415,950	238,667	346,667	304,000	285,250	348,300	321,667	322,400	377,000	**328,878**	±51,654
	Treated T0	162	197	94	-	-	-	-	-	-	**151**	±53
	Treated discharge*	2.0	3.0	3.0	-	-	-	-	-	-	**2.7**	±0.58
	Control discharge	55,610	68,951	65,375	-	-	-	-	-	-	**63,312**	±6,906
B-5	Inlet	492,150	531,483	465,767	440,455	465,750	487,600	415,333	410,550	398,667	**456,417**	±43,932
	Treated T0	170	143	176	-	-	-	-	-	-	**163**	±17
	Treated discharge*	6.0	7.0	0.0	-	-	-	-	-	-	**4.3**	±3.8
	Control discharge	164,424	129,819	153,276	-	-	-	-	-	-	**149,173**	±17,664
B-6	Inlet	489,250	512,333	474,500	612,000	654,500	666,050	-	-	-	**568,106**	±86,110
	Treated T0	245	421	403	-	-	-	-	-	-	**356**	±97
	Treated discharge*	0.0	0.0	1.0	-	-	-	-	-	-	**0.33**	±0.58
	Control discharge	57,633	49,600	55,507	-	-	-	-	-	-	**54,247**	±4,162
B-7	Inlet	254,697	288,167	274,833	269,792	200,000	216,667	248,333	187,250	162,667	**233,601**	±43,654
	Treated T0	62	49	49	-	-	-	-	-	-	**53**	±7.2
	Treated discharge*	8.0	1.0	2.0	-	-	-	-	-	-	**3.7**	±3.8
	Control discharge	43,941	46,563	51,359	-	-	-	-	-	-	**47,288**	±3,762
B-8	Inlet	254,697	288,167	274,833	269,792	200,000	216,667	248,333	187,250	162,667	**233,601**	±43,654
	Treated T0	66	66	103	-	-	-	-	-	-	**78**	±21
	Treated discharge*	3.0	2.0	4.0	-	-	-	-	-	-	**3.0**	±1.0
	Control discharge	43,941	46,563	51,359	-	-	-	-	-	-	**47,288**	±3,762
F-1	Inlet	410,667	339,500	210,833	323,000	336,000	277,333	438,000	453,200	491,667	**364,467**	±90,791
	Treated T0	322	233	283	-	-	-	-	-	-	**279**	±45

Test cycle	Water type	Organisms ≥50 µm (organisms/m^3)										
		FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	FR9	AVG	STD
	Treated discharge*	9.0	4.0	7.0	-	-	-	-	-	-	**6.7**	±2.5
	Control discharge	127,516	151,054	160,229	-	-	-	-	-	-	**146,266**	±16,874
F-2	Inlet	511,817	501,783	440,267	394,400	431,200	421,200	424,667	291,000	551,250	**440,843**	±76,069
	Treated T0	73	66	28	-	-	-	-	-	-	**55**	±24
	Treated discharge*	1.0	1.0	2.0	-	-	-	-	-	-	**0.67**	±0.58
	Control discharge	244,907	261,883	197,880	-	-	-	-	-	-	**234,890**	±33,157
F-3	Inlet	511,817	501,783	440,267	394,400	431,200	421,200	424,667	291,000	551,250	**440,843**	±76,069
	Treated T0	72	186	63	-	-	-	-	-	-	**107**	±68
	Treated discharge*	1.0	1.0	0.0	-	-	-	-	-	-	**0.67**	±0.58
	Control discharge	244,907	261,883	197,880	-	-	-	-	-	-	**234,890**	±33,157
F-4	Inlet	299,000	257,600	230,667	282,750	281,833	154,000	219,533	193,000	187,467	**233,983**	±49,891
	Treated T0	41	54	77	-	-	-	-	-	-	**57**	±18
	Treated discharge*	0.0	0.0	0.0	-	-	-	-	-	-	**0.0**	0.0
	Control discharge	114,268	148,930	145,200	-	-	-	-	-	-	**136,133**	±19,027
F-5	Inlet	299,000	257,600	230,667	282,750	281,833	154,000	219,533	193,000	187,467	**233,983**	±49,891
	Treated T0	73	39	34	-	-	-	-	-	-	**49**	±21
	Treated discharge*	0.0	0.0	0.0	-	-	-	-	-	-	**0.0**	0.0
	Control discharge	114,268	148,930	145,200	-	-	-	-	-	-	**136,133**	±19,027

FR Field replicate

AVG Average

STD Standard deviation

* The entire volumes of the treated discharge samples were analysed for the counting of organisms ≥50 µm.

Table E.7 Organisms ≥50 µm identified in inlet and control discharge water

Phylum/ subphylum	Species	Test cycle												
		B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	F-1	F-2	F-3	F-4	F-5
Annelida	*Nereid* sp.					X								
	Polychaeta sp.	X	X			X	X	X	X					
	Polydora sp.			X	X	X	X							
	Spionida sp.			X	X									
Bryozoa	*Bryozoa* sp.			X	X		X	X	X					
Cilliophora	*Cilliophora* sp.	X	X							X				
	Tintinnid sp.	X	X	X	X	X	X							
	Tintinopsis sp.							X	X					
Cnidaria	*Cnidaria* sp.			X	X									
Crustacea	*Acartia clausi*	X	X	X	X	X	X	X	X					
	Amphipoda sp.			X	X		X							
	Artemia	X	X	X	X	X	X	X	X					
	Balanus sp.			X	X	X	X	X	X					
	Bosmina longirostris									X	X	X	X	X
	Carcinus zoea			X	X	X								
	Centropages hamatus	X	X	X	X	X	X	X	X					
	Chydorus sphaericus									X	X	X	X	X
	Cyclopoida sp.									X	X	X	X	X
	Daphnia cucculata/ longispina										X	X	X	X
	Diaptomus sp.									X	X	X	X	X
	Eurytemora affinis			X	X	X	X	X	X					
	Evadne nordmanni			X	X	X		X	X					
	Harpacticoid microsetella							X	X					
	Harpacticoid sp.			X	X		X							
	Isopoda sp.			X	X									
	Isopoda, Portunion sp.						X	X	X					
	Mysidacea sp.							X	X					
	Oithona similis	X	X	X	X	X	X	X	X					
	Oncaea borealis	X	X											
	Paracalanus parvus					X	X							
	Podon leuckarti			X	X	X								
	Pseudocalanus minutus	X	X	X	X		X	X	X					
	Temora longicornis	X	X	X	X	X	X	X	X					
Dinophyceae	*Ceratium* sp.	X	X	X	X	X	X	X	X					
Mollusca	*Bivalve veliger, Mytilus*			X	X	X	X	X	X					
	Gastropod veliger	X	X	X	X	X	X	X	X					
	Littorina eggs	X	X											
Platyhelminthes	*Plathyhelminth* sp.						X	X	X					
Rotifera	*Asplanchna* sp.									X				
	Euchlanis sp.												X	X
	Keratella sp.					X				X	X	X	X	X
	Polyarthra sp.												X	X
	Synchaeta sp.	X	X				X			X	X	X	X	X
	Triarthra sp.									X	X	X	X	X
Urochordata	*Larvacea* sp.			X	X									

Organism size class ≥10 and <50 µm

Table E.8 Enumeration of organisms ≥10 µm and <50 µm by microscopy after staining with CMFDA and FDA. The motile organisms without chlorophyll are included in the total number of organisms.

Test cycle	Water type	Organisms ≥10 µm and <50 µm (organisms/mL)									
		Total number of organisms					Motile organisms without chlorophyll				
		FR1	FR2	FR3	AVG	STD	FR1	FR2	FR3	AVG	STD
B-1	Inlet	1,547	1,510	1,778	**1,612**	±145	-	-	-	**-**	-
	Treated discharge	330	312	338	**327**	±13	0.0	0.63	0.0	**0.21**	±0.36
	Treated discharge*	74	-	-	**74**	-	0.0	-	-	**0.0**	-
	Control discharge	129	94	66	**96**	±32	0.0	5.5	3.0	**2.8**	±2.8
	Control discharge*	275	-	-	**275**	-	135	-	-	**135**	-
B-2	Inlet	1,547	1,510	1,778	**1,612**	±145	-	-	-	**-**	-
	Treated discharge	380	350	255	**328**	±65	0.0	0.0	0.0	**0.0**	±0.0
	Treated discharge*	96	-	-	**96**	-	0.0	-	-	**0.0**	-
	Control discharge	129	94	66	**96**	±32	0.0	5.5	3.0	**2.8**	±2.8
	Control discharge*	275			**275**	-	135	-	-	**135**	-
B-3	Inlet	1,809	1,842	1,724	**1,792**	±61	-	-	-	**-**	-
	Treated discharge	67	57	40	**55**	±14	0.50	0.0	1.0	**0.50**	±0.50
	Treated discharge*	49	-	-	**49**	-	2.0	-	-	**2.0**	-
	Control discharge	94	153	166	**138**	±38	20	37	34	**30**	±8.9
	Control discharge*	126	-	-	**126**	-	6.0	-	-	**6.0**	-
B-4	Inlet	1,809	1,842	1,724	**1,792**	±61	-	-	-	**-**	-
	Treated discharge	73	65	75	**71**	±5.2	2.0	1.0	1.0	**1.3**	±0.58
	Treated discharge*	61	-	-	**61**	-	1.0	-	-	**1.0**	-
	Control discharge	94	153	166	**138**	±38	20	37	34	**30**	±8.9
	Control discharge*	126	-	-	**126**	-	6.0	-	-	**6.0**	-
B-5	Inlet	2,263	2,175	1,982	**2,140**	±144	-	-	-	**-**	-
	Treated discharge	135	110	166	**137**	±28	1.0	4.0	1.5	**2.2**	±1.6
	Treated discharge*	22	-	-	**22**	-	0.0	-	-	**0.0**	-
	Control discharge	775	1,460	1,150	**1,128**	±343	140	270	160	**190**	±70
	Control discharge*	388	-	-	**388**	-	72	-	-	**72**	-
B-6	Inlet	1,258	1,147	916	**1,107**	±175	-	-	-	**-**	-
	Treated discharge	42	45	57	**48**	±7.9	1.0	0.0	0.0	**0.33**	±0.58
	Treated discharge*	10	-	-	**10**	-	0.0	-	-	**0.0**	-
	Control discharge	79	78	90	**82**	±6.7	16	28	40	**28**	±12
	Control discharge*	53	-	-	**53**	-	6.5	-	-	**6.5**	-
B-7	Inlet	1,403	1,321	1,316	**1,346**	±49	-	-	-	**-**	-
	Treated discharge	41	31	27	**33**	±7.4	9.0	1.0	2.0	**4.0**	±4.4
	Treated discharge*	3.0	-	-	**3.0**	-	0.50	-	-	**0.50**	-
	Control discharge	243	280	305	**276**	±31	77	100	80	**86**	±13
	Control discharge*	146	-	-	**146**	-	25	-	-	**25**	-

Test cycle	Water type	Organisms ≥10 µm and <50 µm (organisms/mL)									
		Total number of organisms					Motile organisms without chlorophyll				
		FR1	FR2	FR3	AVG	STD	FR1	FR2	FR3	AVG	STD
B-8	Inlet	1,403	1,321	1,316	**1,346**	±49	-	-	-	**-**	-
	Treated discharge	38	31	29	**33**	±4.7	1.0	0.0	1.0	**0.67**	±0.58
	Treated discharge*	2.5	-	-	**2.5**	-	0.0	-	-	**0.0**	-
	Control discharge	243	280	305	**276**	±31	77	100	80	**86**	±13
	Control discharge*	146	-	-	**146**	-	25	-	-	**25**	-
F-1	Inlet	6,053	5,825	6,439	**6,105**	±310	-	-	-	**-**	-
	Treated discharge	2,020	1,940	1,910	**1,957**	±57	0.0	0.0	20	**6.7**	±12
	Treated discharge*	590	-	-	**590**	-	0.0	-	-	**0.0**	-
	Control discharge	1,435	1,840	2,240	**1,838**	±403	0.0	60	100	**53**	±50
	Control discharge*	1,840	-	-	**1,840**	-	60	-	-	**60**	-
F-2	Inlet	5,583	5,263	5,868	**5,572**	±303	-	-	-	**-**	-
	Treated discharge	627	613	453	**564**	±96	0.0	6.7	3.3	**3.3**	±3.3
	Treated discharge*	195	-	-	**195**	-	0.0	-	-	**0.0**	-
	Control discharge	1,510	665	842	**1,006**	±446	10	10	6.7	**8.9**	±1.9
	Control discharge*	323	-	-	**323**	-	10	-	-	**10**	-
F-3	Inlet	5,583	5,263	5,868	**5,572**	±303	-	-	-	**-**	-
	Treated discharge	690	495	516	**567**	±107	0.0	0.0	0.0	**0.0**	±0.0
	Treated discharge*	280	-	-	**280**	-	0.0	-	-	**0.0**	-
	Control discharge	1,510	665	842	**1,006**	±446	10	10	6.7	**8.9**	±1.9
	Control discharge*	323	-	-	**323**	-	10	-	-	**10**	-
F-4	Inlet	4,426	5,487	5,658	**5,190**	±667	-	-	-	**-**	-
	Treated discharge	233	293	180	**235**	±56	0.0	0.0	0.0	**0.0**	±0.0
	Treated discharge*	114	-	-	**114**	-	0.0	-	-	**0.0**	-
	Control discharge	880	851	850	**860**	±17	0.0	25	10	**12**	±13
	Control discharge*	420	-	-	**420**	-	15	-	-	**15**	-
F-5	Inlet	4,426	5,487	5,658	5,190	±667	-	-	-	**-**	-
	Treated discharge	253	241	215	**236**	±19	0.0	0.0	0.0	**0.0**	±0.0
	Treated discharge*	97	--		**97**	-	0.0	-	-	**0.0**	-
	Control discharge	880	851	850	**860**	±17	0.0	25	10	**12**	±13
	Control discharge*	420	-	-	**420**	-	15	-	-	**15**	-

FR Field replicate
AVG Average
STD Standard deviation
* Combined sample, stored and analysed 8 d after discharge

Table E.9 Most probable number of proliferating algae (algal re-growth assay)

Test cycle	Water type	Viable algae (organisms/mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	1,300 (470-3,600)	2,400 (890-6,400)	3,500 (1,200-10,000)	**2,400**	±1,100
	Treated discharge	0.78 (0.25-2.4)	<0.18	0.20 (0.028-1.4)	**0.39**	±0.34
	Control discharge	170 (65-460)	220 (83-590)	49 (16-150)	**146**	±88
B-2	Inlet	1,300 (470-3,600)	2,400 (890-6,400)	3,500 (1,200-10,000)	**2,400**	±1,100
	Treated discharge	0.20 (0.028-1.4)	<0.18	<0.18	**0.19**	±0.012
	Control discharge	170 (65-460)	220 (83-590)	49 (16-150)	**146**	±88
B-3	Inlet	16,000 (5,400-48,000)	3,500 (1,200-10,000)	5,400 (1,600-18,000)	**8,300**	±6,736
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	350 (120-1,000)	920 (290-2,900)	350 (120-1,000)	**540**	±329
B-4	Inlet	16,000 (5,400-48,000)	3,500 (1,200-10,000)	5,400 (1,600-18,000)	**8,300**	±6,736
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	350 (120-1,000)	920 (290-2,900)	350 (120-1,000)	**540**	±329
B-5	Inlet	16,000 (5,400-48,000)	>16,000	>16,000	**>16,000**	-
	Treated discharge	0.45 (0.11-1.8)	<0.18	<0.18	**0.27**	±0.16
	Control discharge	540 (160-1,800)	540 (160-1,800)	920 (290-2,900)	**667**	±219
B-6	Inlet	5,400 (1,600-18,000)	5,400 (1,600-18,000)	16,000 (5,400-48,000)	**8,933**	±6,120
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	920 (290-2,900)	920 (290-2,900)	1,600 (540-4,800)	**1,147**	±393
B-7	Inlet	>16,000	5,400 (1,600-18,000)	9,200 (2,900-29,000)	**10,200**	±5,370
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	350 (120-1,000)	170 (65-460)	130 (47-360)	**217**	±117
B-8	Inlet	>16,000	5,400 (1,600-18,000)	9,200 (2,900-29,000)	**10,200**	±5,370
	Treated discharge	<0.18	<0.18	<0.18	**<0.18**	-
	Control discharge	350 (120-1,000)	170 (65-460)	130 (47-360)	**217**	±117
F-1	Inlet	9,200 (2,900-29,000)	3,500 (1,200-10,000)	9,200 (2,900-29,000)	**7,300**	±3,291
	Treated discharge	0.45 (0.11-1.8)	0.20 (0.028-1.4)	7.9 (2.6-24)	**2.9**	±4.4
	Control discharge	>1,600	>1,600	>1,600	**>1,600**	-

Test cycle	Water type	Viable algae (organisms/mL)				
		FR1	FR2	FR3	AVG	STD
F-2	Inlet	16,000 (5,400-48,000)	5,400 (1,600-18,000)	9,200 (2,900-29,000)	**10,200**	±5,370
	Treated discharge	0.20 (0.028-1.4)	0.20 (0.028-1.4)	<0.18	**0.19**	±0.012
	Control discharge	>1,600	1,600 (540-4,800)	1,600 (540-4,800)	**>1,600**	-
F-3	Inlet	16,000 (5,400-48,000)	5,400 (1,600-18,000)	9,200 (2,900-29,000)	**10,200**	±5,370
	Treated discharge	0.20 (0.028-1.4)	0.20 (0.028-1.4)	0.20 (0.028-1.4)	**0.20**	±0.0
	Control discharge	>1,600	1,600 (540-4,800)	1,600 (540-4,800)	**1,600**	-
F-4	Inlet	16,000 (5,400-48,000)	3,500 (1,200-10,000)	9,200 (2,900-29,000)	**9,567**	±6,258
	Treated discharge	<0.18	<0.18	0.78 (0.25-2.4)	**0.38**	±0.35
	Control discharge	1,600 (540-4,800)	540 (160-1,800)	>1,600	**1,247**	±612
F-5	Inlet	16,000 (5,400-48,000)	3,500 (1,200-10,000)	9,200 (2,900-29,000)	**9,567**	±6,258
	Treated discharge	<0.18	<0.18	0.78 (0.25-2.4)	**0.38**	±0.35
	Control discharge	1,600 (540-4,800)	540 (160-1,800)	>1,600	**1,247**	±612

FR Field replicate
AVG Average
STD Standard deviation
( ) 95% confidence interval

Table E.10 Measurements of algal primary production

Test cycle	Water type	Primary production (DPM)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	2,275	2,353	2,278	**2,302**	±44
	Treated T0	844	839	808	**830**	±20
	Treated discharge	215	18	29	**87**	±110
	Control discharge	53	30	41	**42**	±11
B-2	Inlet	2,275	2,353	2,278	**2,302**	±44
	Treated T0	798	693	708	**733**	±57
	Treated discharge	36	44	41	**41**	±4.0
	Control discharge	53	30	41	**42**	±11
B-3	Inlet	7,802	8,715	8,687	**8,402**	±519
	Treated T0	1,075	933	513	**841**	±292
	Treated discharge	0.0	0.0	0.0	**0.0**	±0.0
	Control discharge	91	122	107	**107**	±16
B-4	Inlet	7,802	8,715	8,687	**8,402**	±519
	Treated T0	885	755	505	**715**	±193
	Treated discharge	3.4	0.0	0.0	**1.1**	±1.9
	Control discharge	91	122	107	**107**	±16
B-5	Inlet	8,401	9,234	10,612	**9,416**	±1,117
	Treated T0	1,458	1,306	1,151	**1,305**	±153
	Treated discharge	19	17	11	**16**	±3.9
	Control discharge	316	497	902	**572**	±300
B-6	Inlet	7,359	6,841	7,792	**7,331**	±476
	Treated T0	657	642	632	**644**	±12
	Treated discharge	1.4	2.6	9.4	**4.4**	±4.3
	Control discharge	196	568	830	**531**	±319
B-7	Inlet	7,675	8,346	8,493	**8,172**	±436
	Treated T0	1,896	1,418	1,063	**1,459**	±418
	Treated discharge	5.1	0.0	0.0	**1.7**	±3.0
	Control discharge	271	378	638	**429**	±189
B-8	Inlet	7,675	8,346	8,493	**8,172**	±436
	Treated T0	1,105	1,099	1,034	**1,079**	±40
	Treated discharge	0.0	0.0	0.0	**0.0**	±0.0
	Control discharge	271	378	638	**429**	±189
F-1	Inlet	9,163	9,401	8,793	**9,119**	±306
	Treated T0	3,755	3,586	3,310	**3,550**	±225
	Treated discharge	445	336	360	**380**	±57
	Control discharge	3,410	3,114	3,314	**3,279**	±151
F-2	Inlet	5,470	5,252	5,284	**5,335**	±118
	Treated T0	1,888	791	1,528	**1,403**	±559
	Treated discharge	317	270	292	**293**	±23
	Control discharge	1,537	1,619	1,337	**1,498**	±145

Test cycle	Water type	Primary production (DPM)				
		FR1	FR2	FR3	AVG	STD
F-3	Inlet	5,470	5,252	5,284	**5,335**	±118
	Treated T0	2,494	2,469	1,999	**2,321**	±279
	Treated discharge	344	297	252	**298**	±46
	Control discharge	1,537	1,619	1,337	**1,498**	±145
F-4	Inlet	6,072	6,198	6,088	**6,119**	±68
	Treated T0	798	2,391	2,604	**1,931**	±987
	Treated discharge	77	88	68	**78**	±10
	Control discharge	1,340	1,166	1,007	**1,171**	±166
F-5	Inlet	6,072	6,198	6,088	**6,119**	±68
	Treated T0	2,096	1,945	2,166	**2,069**	±113
	Treated discharge	152	101	83	**112**	±36
	Control discharge	1,340	1,166	1,007	**1,171**	±166

DPM Disintegrations per minute
FR Field replicate
AVG Average
STD Standard deviation

Table E.11 Algal phyla and species identified in inlet water and their capability of growth under the conditions applied in the algal re-growth assay

Phylum/ subphylum	Species	Test cycle													Capable of growing in re-growth assay
		B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	F-1	F-2	F-3	F-4	F-5	
Bacillario-phyceae	*Aulacoseira* sp.									X					X
	Cerataulina pelagica					X									X
	Chaetoceros affinis			X	X	X	X	X	X						X
	Chaetoceros brevis			X	X										X
	Chaetoceros compressus	X	X	X	X										X
	Chaetoceros danicus			X	X										X
	Chaetoceros simplex			X	X										
	Chaetoceros subtilis			X	X										X
	Chaetoceros wighamii					X									X
	Closterium kuetzingii			X	X		X								X
	Cyclostephanus dubius									X					
	Cyclotella meneghiniana										X	X			
	Cyclotella stelligera										X	X			X
	Dactyliosen fragilissimus					X	X	X	X						X
	Ditylum brightwellii						X								X
	Fragilaria capucina									X	X	X			X
	Fragilaria fasciculata									X					X
	Fragilaria pulchella												X	X	X
	Leptocylindrus danicus			X	X			X	X						X
	Licmophora sp.	X	X	X	X	X									X
	Pleurosigma elongatum			X	X	X									X
	Porosira glacialis					X	X								X
	Protoceratium reticulatum					X									
	Rhizosolenia styliformis	X	X												X
	Skeletonema costatum			X	X	X		X	X						X
	Stephanodiscus hantzschii										X	X	X	X	
	Stephanopyxis turris					X									X
	Tabellaria fenestrata									X	X	X	X	X	X
	Thalassionema nitzschioides	X	X												X

Phylum/ subphylum	Species	Test cycle B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	F-1	F-2	F-3	F-4	F-5	Capable of growing in re-growth assay
Chloro-phyceae	*Ankistrodesmus gracilis*									X					X
	Chlamydomonas sp			X	X					X					X
	Closterium macilentum												X	X	X
	Coelastrum cambricum										X	X			
	Cosmarium reniforme												X	X	
	Cosmarium subdepressum										X	X			X
	Crucigenia fenestra									X					
	Crucigenia tetrapedia												X	X	
	Crucigeniella rectangularis									X	X	X	X	X	
	Dictyosphaerium pulchellum												X	X	X
	Dictyosphaerium subsolitarium										X	X			
	Elakatothrix biplex										X	X	X	X	
	Golenkinia radiata									X			X	X	X
	Lagerheimia subsalsa										X	X			X
	Micratinium pusillum										X	X			
	Oocystis borgei										X	X	X	X	X
	Pediastrum cf. *boryanum*									X	X	X	X	X	X
	Pediastrum duplex										X	X			X
	Pediastrum tetras												X	X	
	Pseudostaurastrum limneticum										X	X	X	X	X
	Scenedesmus acuminatus									X	X	X	X	X	X
	Scenedesmus cf armatus									X			X	X	X
	Scenedesmus dimorphus												X	X	X
	Scenedesmus linearis										X	X			X
	Scenedesmus quadricauda										X	X			X
	Scenedesmus serratus										X	X			X
	Scenedesmus subspicatus									X					X
	Staurastrum chaetoceras										X	X			
	Teilingia granulata												X	X	
	Tetraedron caudatum										X	X			
	Tetraselmis sp.	X	X	X	X	X	X	X	X						X
	Tetrastrum triangulare/ komarekii										X	X			X
Chryso-phyceae	*Mallomonas* spp.									X					
	Cryptomonas ovata									X			X	X	X
	Anabaena smithii										X	X			X
Desmidiaceae	*Closterium limneticum*										X	X			X
Dinophyceae	*Alexandrium* sp.			X	X										
	Amphidinium sp.	X	X												X
	Ceratium fusus						X								
	Ceratium tripos							X	X						
	Gymnodinium spp.			X	X										X
	Gyrodinium glaucum							X	X						
	Katodinium glaucum	X	X												X
	Katodinium rotundatum						X								
	Peridiniopsis polonicum									X					
	Prorocentrum micans			X	X	X	X	X	X						X
	Protoperidinium depressum			X	X	X									X

Organism size class <10 µm (bacteria)

Table E.12 Enumeration of heterotrophic bacteria

Test cycle	Water type	Heterotrophic bacteria (CFU/mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	72,700	65,500	65,700	**67,967**	±4,100
	Treated T0	>2,000	82	68	**717**	±1,112
	Treated discharge	6.5	6.0	3.0	**5.2**	±1.9
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
B-2	Inlet	72,700	65,500	65,700	**67,967**	±4,100
	Treated T0	105	115	118	**113**	±6.6
	Treated discharge	12	4.0	3.0	**6.3**	±4.9
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
B-3	Inlet	127,000	146,000	99,100	**124,033**	±23,590
	Treated T0	114	63	53	**77**	±32
	Treated discharge	111	48	35	**65**	±41
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
B-4	Inlet	127,000	146,000	99,100	**124,033**	±23,590
	Treated T0	64	25	40	**43**	±19
	Treated discharge	90	25	23	**46**	±38
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
B-5	Inlet	18,650	6,400	73,600	**32,883**	±35,790
	Treated T0	6.5	<1.0	1.0	**2.8**	±3.2
	Treated discharge	93	58	30	**60**	±31
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
B-6	Inlet	32,250	40,500	29,500	**34,083**	±5,725
	Treated T0	lost	96	65	**81**	±22
	Treated discharge	165	238	100	**168**	±69
	Control discharge	>200,000	>200,000	>200,000	**>200,000**	-
B-7	Inlet	36,350	30,900	38,200	**35,150**	±3,795
	Treated T0	81	66	56	**68**	±13
	Treated discharge	206	120	65	**130**	±71
	Control discharge	155,000	161,500	140,000	**152,167**	±11,026
B-8	Inlet	36,350	30,900	38,200	**35,150**	±3,795
	Treated T0	53	35	53	**47**	±11
	Treated discharge	30	19	21	**23**	±5.9
	Control discharge	155,000	161,500	140,000	**152,167**	±11,026
F-1	Inlet	57,000	52,700	60,500	**56,733**	±3,907
	Treated T0	196	23	27	**82**	±98
	Treated discharge	64	59	64	**62**	±2.8
	Control discharge	38,400	17,100	49,500	**35,000**	±16,465
F-2	Inlet	23,900	22,700	30,500	**25,700**	±4,200
	Treated T0	289	91	127	**169**	±105
	Treated discharge	30	32	18	**27**	±7.5
	Control discharge	35,200	18,300	34,500	**29,333**	±9,562

Test cycle	Water type	Heterotrophic bacteria (CFU/mL)				
		FR1	FR2	FR3	AVG	STD
F-3	Inlet	23,900	22,700	30,500	**25,700**	±4,200
	Treated T0	109	77	27	**71**	±41
	Treated discharge	14	36	32	**27**	±12
	Control discharge	35,200	18,300	34,500	**29,333**	±9,562
F-4	Inlet	72,050	48,600	60,500	**60,383**	±11,725
	Treated T0	166	141	314	**207**	±94
	Treated discharge	223	205	150	**193**	±38
	Control discharge	54,350	79,100	45,900	**59,783**	±17,254
F-5	Inlet	72,050	48,600	60,500	**60,383**	±11,725
	Treated T0	246	118	73	**146**	±89
	Treated discharge	128	86	105	**106**	±21
	Control discharge	54,350	79,100	45,900	**59,783**	±17,254

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

Table E.13 Enumeration of enterococci

Test cycle	Water type	Enterococci (CFU/100 mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	225	155	71	**150**	±77
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	23	21	22	**22**	±1.0
B-2	Inlet	225	155	71	**150**	±77
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	23	21	22	**22**	±1.0
B-3	Inlet	398	313	238	**316**	±80
	Treated discharge	<1.0	<1.0	<1.0	**<1.00**	-
	Control discharge	6.0	11	9.5	**8.8**	±2.6
B-4	Inlet	398	313	238	**316**	±80
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	6.0	11	9.5	**8.8**	±2.6
B-5	Inlet	27	34	83	**48**	±31
	Treated discharge	<1.0	1.5	<1.0	**1.2**	±0.29
	Control discharge	6.0	10	15	**10**	±4.5
B-6	Inlet	140	90	39	**90**	±51
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	<1.0	2.5	4.0	**2.5**	±1.5
B-7	Inlet	84	56	38	**59**	±23
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	15	7.0	28	**17**	±11
B-8	Inlet	84	56	38	**59**	±23
	Treated discharge	<1.0	1.0	<1.0	**<1.0**	-
	Control discharge	15	7.0	28	**17**	±11
F-1	Inlet	3.0	3.0	4.0	**3.3**	±0.58
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	6.0	5.5	10	**7.2**	±2.5
F-2	Inlet	12	10	8.0	**10**	±2.0
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	35	18	18	**24**	±9.8
F-3	Inlet	12	10	8.0	**10**	±2.0
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	35	18	18	**24**	±9.8
F-4	Inlet	10	17	24	**17**	±7.0
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	13	3.5	10	**8.8**	±4.9
F-5	Inlet	10	17	24	**17**	±7.0
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	13	3.5	10	**8.8**	±4.9

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

Table E.14 Enumeration of *E. coli*

Test cycle	Water type	*E. coli* (CFU/100 mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	75	<10	15	**33**	±36
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
B-2	Inlet	75	<10	15	**33**	±36
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
B-3	Inlet	452	336	364	**384**	±61
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
B-4	Inlet	452	336	364	**384**	±61
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
B-5	Inlet	10	20	10	**13**	±5.8
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
B-6	Inlet	<10	10	<10	**<10**	-
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
B7	Inlet	52	25	31	**36**	±14
	Treated discharge	<1	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
B-8	Inlet	52	25	31	**36**	±14
	Treated discharge	<10	<10	<10	**<10**	-
	Control discharge	<10	<10	<10	**<10**	-
F-1	Inlet	1.5	1.0	1.0	**1.2**	±0.29
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	<1.0	<1.0	<1.0	**<1.0**	-
F-2	Inlet	19	11	22	**17**	±5.7
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	1.0	3.0	2.0	**2.0**	±1.0
F-3	Inlet	19	11	22	**17**	±5.7
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	1.0	3.0	2.0	**2.0**	±1.0
F-4	Inlet	31	19	-	**25**	±8.5
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	<1.0	<1.0	<1.0	**<1.0**	-
F-5	Inlet	31	19	-	**25**	±8.5
	Treated discharge	<1.0	<1.0	<1.0	**<1.0**	-
	Control discharge	<1.0	<1.0	<1.0	**<1.0**	-

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

Table E.15 Enumeration of *Vibrio cholerae*

Test cycle	Water type	*Vibrio cholerae* (CFU/100 mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-2	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-3	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-4	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-5	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-6	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-7	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-8	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
F-1	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
F-2	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
F-3	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
F-4	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
F-5	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

APPENDIX F

Quality control and quality assurance for performance evaluation in land-based test facility with Trojan Marinex^{TM} BWT 500

Quality control and quality assurance	Description	Overall responsible
Quality control, data from laboratory analyses and database entries	All results related to samples and laboratory analyses are stored in relevant databases. All data entries in databases have been quality controlled. Laboratory records are filed in the DHI archives.	Last data entry 2013.08.09 Camilla Hedberg
Quality control, onsite data from the DHI Maritime Technology Evaluation Facility, Hundested	Data related to the activities at the test facility were logged for each individual test cycle. Onsite data records are filed in the DHI archives.	Quality control last data set 2013.09.18 Morten Bjergstrøm
Quality control, interim test cycle reports	All data related to a specific test cycle have been reported in interim test cycle reports. Reports were written by members of the project team upon completion of quality control of all data sets. Each interim test cycle report was quality controlled.	Quality control last interim report 2013.09.06 Torben Madsen
Quality control, final report	Data and data interpretation related to the present performance evaluation have been quality controlled, and all data are truly and accurately presented in the final report.	Quality control final report 2013.10.13 Torben Madsen
Quality control, final revised report	Data and data interpretation related to the present performance evaluation have been quality controlled, and all data are truly and accurately presented in the final report.	Quality control final revised report 2013.11.27 Torben Madsen
Quality assurance (final report)	The performance evaluation in land-based test facility of Trojan Marinex™ BWT 500 complies with the conditions outlined in the QMP, QAPP and SOPs. The performance evaluation was conducted in compliance with the IMO G8 guidelines and ETV protocol. The guidance requirements for biological efficacy test cycles were consistently fulfilled except for minor deviations, which were considered negligible, and are appropriately addressed in the final report.	Quality assurance of project 2013.10.28 Louise Schlüter
Quality assurance (final revised report)	The performance evaluation in land-based test facility of Trojan Marinex™ BWT 500 complies with the conditions outlined in the QMP, QAPP and SOPs. The performance evaluation was conducted in compliance with the IMO G8 guidelines and ETV protocol. The guidance requirements for biological efficacy test cycles were consistently fulfilled except for minor deviations, which were considered negligible, and are appropriately addressed in the final revised report.	Quality assurance of project 2013.11.28 Louise Schlüter

APPENDIX G

Certificate of compliance, Letter of Acceptance, ISO 9001 certificate, accreditation and GLP authorization

COPY

Lloyd's Register Certificate of Compliance

Office: **Lloyd's Register EMEA**
Copenhagen Design Support Centre, Statutory Section
Strandvejen 104A, 2nd floor
DK-2900 Hellerup
Denmark

Date: **09 May 2012**

This certificate is issued to **DHI Ballast Water Centre, Denmark**

DHI Ballast Water Centre, Denmark

The Document(s) listed in paragraph 1 of the appendix have been examined for compliance with:

- Resolution MEPC.174(58), Annex part 2

and are found to comply from quality assurance and quality control aspects subject to the following:

1.1. It is required to maintain full and accurate log files in order to demonstrate correct quality measures

1.2. The Quality Assurance Project Plan is a project specific document and should as such be subject to review and commenting prior to each project start-up.

1.3. This design appraisal document is to be kept together with quality management plan.

1.4. Subject certificate is valid until 15 June 2015.

1. The documents listed below have been examined

Drawing No.	Rev.	Title	Status	Date
Date: 07 Sep 2011	**2.3**	**Quality Management Plan**	**B**	**09 May 2012**

2. The documents listed below have been considered together with the submitted documents in the appraisal

Drawing No.	Rev.	Title
11810704	**02**	**Quality Assurance Project Plan**

Appraisal Status Key

B Examined and found to comply with §2.2, Part 2 of the annex of IMO Resolution MEPC 174 (58)

Martin Schabert
Statutory Department
Copenhagen Design Support Centre
Surveyor to Lloyd's Register EMEA

LLOYD'S REGISTER EMEA
Lloyd's Register
M. Schabert
COPENHAGEN DESIGN SUPPORT CENTRE

A member of the Lloyd's Register Group

U.S. Department of Homeland Security
United States Coast Guard

Commandant
United States Coast Guard

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Fax: (202) 372-1925

16714/162.060/DNV
2012-3019
JUN 11 2013

LETTER OF ACCEPTANCE

Det Norske Veritas (USA) Inc.
North America Maritime
Approval Class and Statutory
1400 Ravello Dr.
Katy, TX 77449

Dear Mr. Vareide:

We have reviewed your application of October 11, 2012 and hereby accept the Det Norske Veritas (DNV) AS, located in Høvik, Norway as an *Independent Laboratory*, as defined by 46 CFR 159.001-3, for the evaluation, inspection, and testing of ballast water management systems.

As an accepted *independent laboratory* you are required to independently evaluate, inspect, and test ballast water management systems for compliance with the standards and regulations of 46 CFR 162.060. You are also required to submit your results to the U.S. Coast Guard Marine Safety Center.

This letter of acceptance also acknowledges that separate arrangements exist between DNV and other independent laboratories accepted by the U.S. Coast Guard, as per the enclosure, to perform certain tests on your behalf. DNV is responsible for the accuracy and completeness of these sub-laboratories and is required, whenever practicable, to have a qualified representative present during testing. You are also required to include the results from each sub-laboratory in your report to the U.S. Coast Guard.

Information contained in this letter and enclosure will be listed on the *Coast Guard Maritime Information Exchange* (CGMIX) at *http://cgmix.uscg.mil* under accepted laboratories for approval series 162.060. This online searchable database is the official listing of all U.S. Coast Guard accepted laboratories for testing of materials and equipment.

This letter of acceptance will remain in effect until terminated. You are required to notify us in writing within 30 days of any changes to the information in your application, this letter, or the enclosure.

Sincerely,

C. K. MARCY
Commander, U.S. Coast Guard
Chief, Systems Engineering Division
By direction

Enclosure

16714/162.060/DNV
2012-3019
JUN 1 1 2013

Det Norske Veritas AS Attn: Mr. Jad Mouawad Veritasveien 1 1363 Høvik Norway Tel: +47 480 50 902 jad.mouawad@dnv.com	***Accepted Facility***: Performs evaluation, inspection, and testing. 162.060-42 Responsibilities for Independent Laboratories
DHI-Denmark Attn: Torben Madsen Tel: +45 45 16 9310 tma@dhigroup.com (Main Office and Enviornmental Laboratory) Agern Allé 5 DK-2970 Hørsholm Denmark (Maritime Technology Evaluation Facility) Færgevejen, DK-3390, Hundested, Denmark	***Sub-Laboratory***: Performs evaluation, land-based and shipboard testing. 162.060-20 Design and Construction requirements 162.060-26 Land-based testing 162.060-28 Shipboard testing
Det Norske Veritas Certification AS (Product Compliance Unit) Attn: Vibeke Vigmostad N-1322 Høvik, Norway Tel: +47 67 57 99 00 vibeke.vigmostad@dnv.com	***Sub-Laboratory***: Performs evaluation and environmental testing only. 162.060-20 Design and Construction requirements 162.060-30 Environmental (component) testing

ENCLOSURE

DNV BUSINESS ASSURANCE

MANAGEMENT SYSTEM CERTIFICATE

Certificate No. 109333-2012-AQ-DEN-DANAK

This is to certify that

DHI Group

has been found to conform to the management system standard:

DS/EN ISO 9001:2008

This certificate is valid for the following product or service ranges:

Consulting, software, research & development and laboratory testing, analysis & products within the area of water, environment & health

Locations included in the certification will appear in the appendix.

Place and date:

Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

This certificate is valid until:

2015-01-10

The audit has been performed under the supervision of:

DANAK
SYSTEM Reg.nr. 5001

Jan Carsten Schmidt
Lead Auditor

Jens Peter Høiseth
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

ACCREDITED UNIT: DET NORSKE VERITAS, BUSINESS ASSURANCE, DANMARK A/S, TUBORG PARKVEJ 8, 2., DK-2900, HELLERUP, DANMARK, TEL:+45 39 45 48 00, WWW.DNVBA.COM

DNV BUSINESS ASSURANCE

APPENDIX TO CERTIFICATE

This appendix refers to certificate no. 109333-2012-AQ-DEN-DANAK

DHI Group

Locations included in the certification are as follows:

Site Address	Scope:
Agern Allé 5 2970 Hørsholm, Denmark	Consulting, MIKE© by DHI Software Development, Sales & Support, Solutions Software Development, Research, Development & Innovation and Laboratory Analysis, Testing & Products
INCUBA Science Park, Gustav Wieds Vej 10 8000 Århus, Denmark	Consulting, Solutions Software Development and Research, Development & Innovation
Drakegatan 6, 412 50 Göteborg, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Kyrkogatan 3, 222 22 Lund, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Svartmangatan 18, 111 29 Stockholm, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Honnörsgatan 16, Box 3287, 350 53 Växjö, Sweden	Consulting, MIKE© by DHI Software Sales & Support

Place and date:

Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

This certificate is valid until:

2015-01-10

The audit has been performed under the supervision of:

DANAK
SYSTEM Reg.nr. 5001

Jan Carsten Schmidt
Lead Auditor

Jens Peter Høiseth
Managing Director

COPY

DANAK

Accreditation to testing

Company: **DHI**

Agern Allé 5
DK-2970 Hørsholm

Registration number: **26**

Valid: **24-10-2012 to 31-07-2015**

Scope:

Testing

Product
- **Biological items**
- **Chemicals and chemical products**
- **Construction products**
- **Environmental samples**

Test Type
- **Biological and biochemical testing**
- **Chemical testing**
- **Microbiological testing**
- **Ionising radiation and radiochemistry**
- **Sampling**

Testing is performed according to the current list of test methods approved by DANAK.

The company complies with the criteria in EN ISO/IEC 17025:2005 – General requirements for the competence of testing and calibration laboratories and demonstrates technical competence for the defined scope and the operation of a quality management system (refer joint ISO-ILAC-IAF Communiqué dated January 2009, www.danak.dk).

Issued the 24 October 2012

f. **Jesper Høy** / **Kirsten Jebjerg Andersen**

In case of any disputes, the Document in Danish language shall have priority.

COPY

DANAK

GOOD LABORATORY PRACTICE

STATEMENT OF COMPLIANCE

Laboratory inspection and study audits for compliance with the OECD Principles for Good Laboratory Practice were carried out at

Laboratory: DHI

on

Dates: 21st and 22nd October 2011

The laboratory inspection and study audits have been carried out in accordance with the regulation settled in Order No. 906 of 14th September 2009 from the Danish Ministry of Environment. The laboratory has been monitored for GLP Compliance within the following scope:

Type of products:

- *Industrial chemicals*
- *Pesticides*
- *Biocides*

Type of tests:

- *Environmental toxicity studies on aquatic and terrestrial organisms.*
- *Studies of behaviour in water, soil and air, bioaccumulation*

The laboratory was found to be operating in compliance with the OECD Principles of Good Laboratory Practice.

Date: 08 August 2012

Jesper Høy
Managing director, DANAK

Kirsten Jebjerg Andersen
GLP inspector, DANAK